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Natural and Antropic Geomorphological Changes in the Inlet of Patos Lagoon Before and After its Fixation

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ABSTRACT

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Comparative analysis of historical records of geocoded charts from the Patos Lagoon inlet between the years of 1883 and 1956 indicates that the shoreline at the south of the west jetty experimented a progradation of the order of 1000 m. This effect was more intense between 1914 and 1917 stabilizing after this period. During the same period, shoreline progradation to the north of the structure reached 60 m and 13.4 m respectively at distances of 500 m and 1,000 m of the west jetty. At the inlet, significant changes occurred in the east margin which is extremely dynamic when compared with the west margin. Morphologically, prior to the jetties construction the east point displayed a convex side facing the ocean. Fixation of the east jetty reoriented the point by changing its original form to a concave side facing the ocean. Sediment volume changes between the jetties considering a width of 720 m and a length of 4,020 m during distinct years indicated differences between periods of climatic extremes. Natural deepening and siltation were respectively associated to a historical flood and a extended drought . The same behavior was identified for the sand bar nucleus which respectively increase and decrease its sediment volume according hydrodynamic changes associated to the climatic variations.

ADDITIONAL INDEX WORDS: *jetties, bathymetrics charts, GIS – Geographic Information System*.

INTRODUCTION

The possibility of geocoded historical charts of the connection channel, Northern Channel (NC) between Patos Lagoon and the Atlantic Ocean confected by hydraulic engineers of the former "Comissão de melhoramentos da Barra de Rio Grande (BRG)" might offer the unique opportunity to evaluate the morphologic and volumetric changes caused by the natural and antropic hydrodynamic variations which are caused by the engineering works of fixation of the Northern Channel over that bar. The BRG system is connected to the inlet of Patos Lagoon, which access is fixated by two jetties which link the southern extremity of the Lagoon to the Atlantic Ocean (Figure 1).

The construction of the BRG jetties was the bigger coastal engineering work ever performed in Brazil. The studies to the construction started in 1883 and the construction itself has begun and has been concluded respectively in 1910 and 1917. Up to 1911, the works were only preliminary. The actual construction was done between 1911 and 1915, period in which the effects of the work over the BRG were visible, particularly from 1914 on, a rainy year which caused severe and longstanding ebbs in the Northern Channel. The east jetty was only concluded in the period between 1922 and 1928 (MOTTA, 1969). Both converging jetties present a south-easterly orientation and have reached in period of their conclusion the isobath of -10 m with the west jetty shorter than the eastern one, both extending respectively 4,012 m and 4,250 m from their base.

The objective of this work is to evaluate the evolution of the coastal line and the sediment volume variation in the Northern Channel and over the nucleus of the BRG during the previous and after period of the construction of the jetties (1883 to 1956), aiming at establishing possible relation between morphologic and volumetric changes, and hydrodynamic and climatologic patterns.

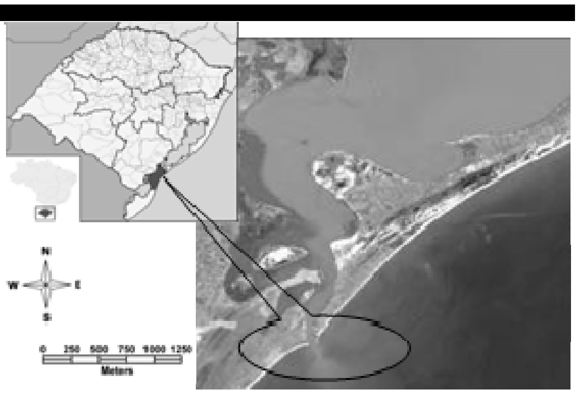

Figure 1. Location of the System of Rio Grande´s Bar. Inlet of Patos Lagoon. RS. Brazil.

METHODS

Bathymetric plants of 1883 to 1956 (VASSÃO, 1959) of the region of BRG and adjacent area, were digitized in jpg format using a scanner A3. The vetorization and referenced geographically (geocoded) were performed in the GeoMedia Professional v6.0 with is a Geographic Information System(GIS) software taking as a basis Google Earth to which two plants dated 1883 and 1956 containing reference points for triangulation of the area of the construction of the jetties and its position were added. Those plants were superposed as layers and had their outlines adjusted to an Ikonos satellite available image of 2006. The standardized grid (1:20000 scale) available in all the plants containing the location of points of triangulation and the definition of a few more points in the grid, was used as reference for the extraction of 14 control points for geocoded.

For each plant were rasterized and implemented the geocoded, the calculation of the distance of the coastline with purpose of being used in the GeoMedia GRID package for carrying out the calculations of developments of the BRG and of the sediment volume between the jetties.

For the period that comprehends 1885 to 1917 we have measured the length of the spits´ formation in the eastern coast of the inlet, from the beginning of embayment up to the end of the spit. The measures of width were made at a distance of 5 to 10 meters from edge of the sand spit. To the period of 1918 to 1956, we found spits only in east side of the inlet, external and internal to the eastern jetty. The measures vary according to the changes observed in the direction and extension of the spits. The length remained being measured from the beginning of embayment up to the end of the spit. The measure of the width of the external spit to the eastern jetty was performed approximately to the center of the same.

Internally to the jetty we identified the formation of two features. The first one from 1918 and the other one from 1940. The measures of the width of appearance which started their formation in 1918, internal spit second measure (Point 2) at a distance of 638 m of point 1, the third (Point 3) at a distance of 1,070 m from point 1 and the fourth (Point 4) at a distance of 1,500 m from the jetty base.

For the feature which started its formation in 1940, internal spit 2, the measure of length was carried out in the same way, that is, from the beginning of embayment up to the edge of the spit. The measure of the width in Point 1 is at the beginning of embayment, in Point 2 is at a distance of 200 m from the point 1, in Point 3 is at a distance of 450 m from point 1, and point 4, while there were available information for the attainment of the measure, this varied from 570 m to 905 m away from the point 1.

The accretion rates of the coastline adjacent to the jetties, both external and internal, were calculated, from the definition of perpendicular profiles to the coastline and parallels among themselves, defined to intervals of 500 m, up to a maximum distance of 3,000 m, always conditioned to the existence of previous information.

The calculation of the volume of the nucleus of BRG was done from intervals of the isobathymetrics, oscillating between -1 and -8 m when the isobath was closed. Due to the great variation in the nucleus of BRG between the values of (-1,-6) m, (-4,-6) m, (-5,-9) m, a standardization was done so the values found could have a relationship and the averages were used for data comparison.

The ranges defined were: between (-1, -6) m for the period preceding the construction of jetties, and (-5,-8) m and (-6, -8) m for the period after the construction of jetties. In some specific years, it was not possible to perform the calculations within the range proposed due to the lack of information in the plant.

Through the choice of the area of study, normal periods climatology charts, flood and dry seasons, were selected, and then vetorized and rasterized, carrying the bathymetry data of BRG, generating the DEM, by Spline method (MITÁSOVÁ and MITÁS,1993). Sixty seven (67) profiles were delineated and defined to 60 m regular distances transversal to the corresponding area up to the jetties whole extension, encompassing a distance of 4,020 m.

The bathymetry information of 1914 were not sufficient to generate the calculation of volume, since in 1913 the jetties were in construction. Then the volume was generated from the first 28 profiles. In the year of 1917 were used the profiles from 1 to 63, because there were insufficient information. For the other years all 67 profiles were used, taking in account a width of approximately 720 m between the jetties´tip and an extension of 4,020 m (Figure 2).

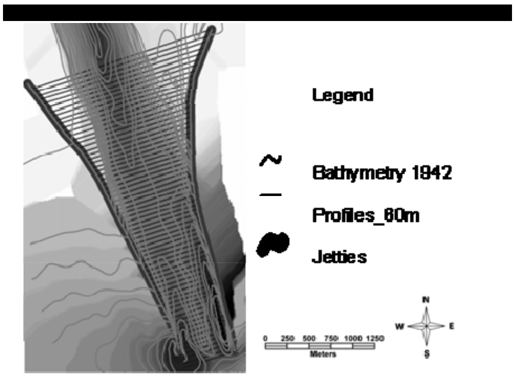

Figure 2 – Profiles between the jetties of BRG.

The volume calculation was performed based on closed polygons and rectangular grids of DEM from the central value of each grid cell, corresponding to height multiplied by the value of the available area. Thus, the volume is given by the equation:

$$Vt = Ac \sum_{i=1}^{n} Zi$$

Where:
Ac = value of the area corresponding to each cell;
Zi = value of the height of each cell;
n = number of cells

The calculation taking in account the bathymetry. The upper and lower parts correspond respectively the volumes of water and sediment.

The plants selected for analysis, were identified through information made available by the National Institute of Space Research (INPE) and represent years of extreme climatological events corresponding to El Niño and La Niña, as well as normal years without climatic anomalies with the goal of establishing a comparative analysis of results.

RESULTS AND DISCUSSION

Sand spit and coastline evolution

A comparative analysis of the coastline on plants from 1885 to 1909 (Figure 3(a)), earlier dates to the construction of the jetties of the BRG, show the extreme variability of coastline. It is possible to see in the eastern margin the accretion of the sand spit directed to the ocean, often penetrating into the lagoon’s inlet characterizing several sequences of formation and extinction of “Lagamar”, which is a Portuguese definition for small embayments isolated from the inlet eastern edge, evidencing an effective sand transport from northeast to southwest by means of littoral drift. On the southern side of the inlet, it is possible to perceive the effective accretion of the coastline, evidencing the effect of "hydraulic jetty" in retain the sediment source transported by the littoral drift from southwest to northeast. Such evidences were then consolidated by the work of MOTTA (1969) and PITOMBEIRA (1975), which have made more evident bidirectional characteristics of bottom sediment transport in the form of bedload along the coast of RS.

During the period of 1885 to 1915 it was possible to observe that swash bars in the west side were formed and extinct alternately. In the inlet east side the spit were always frequent and bigger in dimension, decreasing in size and forming new ones. During the period of construction of the jetties, the formation of spits began to be defined in the eastern side of the inlet with a concave profile, unlike the convex previous one which was directed to the ocean. The formation of new spits can be observed from 1918 on and later after 1940 (Figures 3(b) and 3(c)).

The external spit maintains its average length (1918 to 1956) 211.7 m and 117.3 m in width. An internal spit starts its formation with its length in 1375.9 meters in the period that comprehends the year of 1918 up to 1956 and the measures of widths average were of 154 m, 87.7 m, 109.4 m, and 86.8 m. Between 1940 and 1956 one more spit with length of 652.7 m starts to take form. The new spit has a tendency to increase its size because in the past 3 years its length was greater than 700 m, and the averages of the measures of widths were of 179.7 m, 162.2 m, 168.6 m, and 133.9 m.

During the construction of the BRG jetties (Figure 3(b)) it was possible to follow coastline changes, in which is possible to identify accretion of the western margins and changes in the eastern one. The second one presents little accretion near the jetty and a significant recede in more than 1,000 m from the base of the jetty. A quick change can be perceived in the period of 1911 to 1928, during the construction of the jetties, especially to the south of the structure.

For the west jetty, external to the inlet, was identified a rate of accretion the coastline of 4.74 m/year (1885-1911) (Figure 3(a)), 1.11m/year (1911-1928) (Figure 3(b)) and 1.36 m/year (1928-1956) (Figure 3(c)). Internally it was measured 1.21 m/year (1885-1911), 0.08 m/year (1911-1928) and -0.12 m/year (1928-1956).

The rates for the eastern jetty, external to the inlet, it is possible to see a recede of the coastline with a rate of erosion of –2.89 m/year (1885-1911), -1.91 m/year (1911-1928) and -0.45 m/year (1928-1956). Internally it was measured the drawback of the coastline to the north with -0.47 m/year (1885-1911), -2.82 m/year (1911-1928) and -2.13 m/year (1928-1956). At the eastern jetty, in the southern direction, the coastline progressed in 3.34m/year (1911-1928) and 0.07m/year (1928-1956). LÉLIS and CALLIARI (2004) verified through the analysis of aerial photographs of the coast of RS an accretion in coastline to the south of the structure in 4.10 m/year and a rate of -1.44 m/year 3,000m of distance north to the base of the eastern jetty.

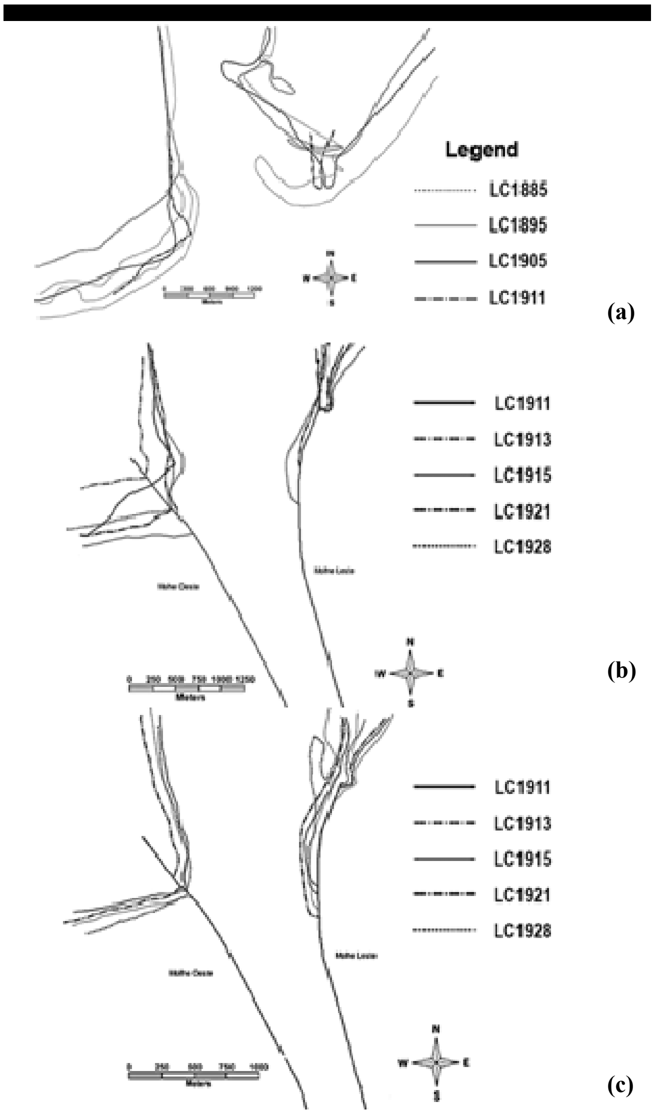

Figure 3 – Coastline changes before(a), during(b) and after(c) jetties´ construction, from 1885 to 1956.

After the end of the construction of the jetties the changes were not as extreme as expected. What happened was a stabilization of the coastline along the western jetty and the amendments to the coastline along the eastern jetty, in which spits were formed the internal part of the jetty.

The considerable accretion to the south of the structure demonstrates the effectiveness of net sediment transport (longshore drift) pattern from southwest to northeast in this specific segment of the coast. Morphologically, the eastern spit presented a convex profile turned toward the ocean with an arenaceous sand spit which tends to extend itself within the inlet, forming features regionally denominated "Lagamares" (Figure 3(a)).

On the other hand, the fact that is possible to find a small accretion in the coastline to the north and close to the structure (500 m) with a recede at a distance of 1,000 m of the coastline itself, demonstrates the effectiveness of a secondary sediment transport from northeast to southwest. The behavior of coastline in these two sectors strengthens the bidirectional character of sedimentation transport along the coast of RS, such as MOTTA(1969) and PITOMBEIRA (1975).

Before the fixation of the jetties the sand spits had convex form facing the ocean(Figure 3(a)).The fixation of the eastern jetty on the spit reshaped itself by changing the form of the profile turned toward the ocean making it concave. Such changes are due to the amplification of flood currents during southern storms, which form currents that penetrate in the internal side of the west jetty, extending throughout all the extension between the jetties alternating the direction to northwest thereby modifying morphodynamically the spit (Figure 3(b)).

Evolution of the Rio Grande Bar (BRG) and Northern Channel (NC)

The amendments on the BRG and NC before the construction of the jetties(1885-1909) shows that both presented significant changes, due to the climatic and seasonal changes as a response of variations in response to the variation of the flow of the lagoon induced by the water volume in the drainage basin and by the action of oceanic undulation. As a result, it is possible to perceive that the channel in its marine portion acquired a bifurcated form, varying also its direction, migrating from southwest to southeast, remaining more time in this last position. This might indicate that the last orientation would be the best guidance, which would maximize the flow of the lagoon and consequently define the orientation of the two jetties.

The relative importance of Patos Lagoon's flux and the action of the waves due to wind direction changes were pointed out by CALLIARI (1980), showing the moment in which the winds action, especially NE, NNE and ENE converging with the axis of the lagoon, generates a water level decline in direction to the sea, working as an ebb to the hydraulic footstep generated by the increase of the level of the lagoon to the north. Similar effects are generated by winds in the SSW and WSW quadrant which are presented with the same orientation of the axis of the lagoon, but with the opposite orientation. In this sense, a obstruction of the waters in the channel is created, establishing a strong flood flow (CALLIARI, 1980).

Using plants geocoded and SIG it was also possible to observe that the access channel remained at a maximum depth of -5 m, reaching higher depths only in the year of 1886 to -8 m, but then falling to -6 m and -7 m in the following years, between 1891 and 1894. During the construction of the jetties in 1914 and 1915, in a period of an El Niño event, it is possible to note a natural deepening of the channel to -8 m due to the increasing of the water volume in the drainage basin. A new El Niño between 1919 and 1920 deepened the channel for -9m, maintaining this depth until 1928 and changing it to -10m in 1929. From 1929, on it has remained at -10 m only changing to -14 m in 1941, year of a very strong El Niño event, which caused flood in the state. In this plants its also possible calculated the distance between the bars of 1885 and 1956, 1900 and 1956 (before and after construction); 1914 to 1928 (during construction); and from the center of the jetties to the nucleus of BRG after the effective end of the construction of two jetties in 1928. It was made the measurement of the distance of the center of the jetties (the center of the channel of access to the port of Rio Grande) and the core of BRG in 1928. This measure was performed in a period after 1928, following the end of the construction of the jetties. The bar has suffered a progressive displacement since the beginning of the construction of the jetties, while in a previous period the instability was constant. Can be observed too the displacement total variation in the period that comprehends the year of 1885 up to 1956 between the centers of BRG was 5,665 m. Between 1900 and 1956 the amplitude observed was from 5,000 m. An additional measure performed between 1909 (before the beginning of the construction) and 1956 indicated an approximate value of 5,000 m (4,926 m). The value of distance measure falls for 3,366 m in 1914, when most of the work was already done. From 1928 on, due to the end of the construction of the eastern jetty, the average distance between the central point between the western and eastern jetties and the nucleus of BRG changed to 1,767 m to 28 years (from 1928 to 1956). The 1941 flood made this displacement, moving the BRG in 527 m.

Volume variations at the Rio Grande Bar

Although the natural inlet of the Northern Channel was not migrating along the coast, the bar varied annually in terms of depth control, remoteness from the coastline and configuration expressed by orientation, and number and location of natural channels (Motta,1969). In order to identify volumetric changes occurred before, during and after the construction of the jetties, volumetric calculations of the nucleus of the BRG were carried out in the period of 1885 to 1956, emphasizing both, normal and extreme climate situations.

The calculations of the volume of BRG was done corresponding to the years of El Niño, La Niña, and normal years, as well as the isobathymetric intervals. It is possible to observe that before the construction of the jetties, the extreme variability of the bar make it impossible to compare volume changes between periods of extreme climatological events. During the construction similar situations happened because of the great variability of data and also due the lack of information in some of the plants. For after the construction it was possible to define a standard pattern and verified that the volume of BRG during El Niño periods presented an average volume of 2,350,454 m^3, during La Niña 2,793,821 m^3, and in normal periods 2,667,500 m^3. The values found present lower values than the normal period during the event of El Niño (flood period), and higher values during La Niña (prolonged drought). The lack of bathymetric verification in 1941 has prevented the determination of the volume of bar nucleus in that year. The most precise information in that year is reported by MOTTA, in 1969, when the isobathymetric position is shown as -10 m before and after the flood in 1941. It was also possible to identify that drought period had an increase of sediment in the Northern Channel and in the BRG, ocurrin the happening the opposite the ebb period, showing an increasing in sediment volume, both in the BRG and in the NC during periods of drought. The volume variations associated with the different periods might be explained by the variation of the hydrodynamic conditions. Flood periods in the drainage basin tend to increase the flow of the lagoon, causing "natural dredging", both at the edge of the channel and in the BRG, evidencing the predominance of the flood currents on the wave undulatory regime. Contrarily, prolonged droughtperiods may favor the action of undulations, which tend to sediment transport towards right to the inlet.

During and after the jetties' construction, the BRG suffered a progressive displacement holding off from the inlet and the edge of the jetties after the end of their construction. From 1885 to 1909, the total displacement before the beginning of the jetties' construction was of 759 m. From 1911 to 1928, during the jetties' construction the displacement was of approximately 6,000 m, and after the end of the construction, from 1930 to 1956, the average displacement was of 1,500 m.

Sedimentation volume between the jetties

The calculation of volume between the jetties has shown that in extreme climatological periods, characterized by El Niño periods, culminating with the historic flood of 1941, the sediment volume above the depth of -25 m presented values of the order 67,936,800 m^3 in 1919, 65,394,622 m^3 in 1941, and 76,626,202 m^3 in 1947. In the passage of La Niña, which culminated with the drought of 1917, the values were of 77,797,674 m^3 in 1917, 75,118,230 m^3 in 1939, and 73,083,410 m^3 in 1954. In normal periods such as 1915, 1921, 1942 and 1943 it is possible to obtain, respectively, the values of 79,094,864 m^3, 70,396,572 m^3, 66,473,434 m^3, and 67,893,629 m^3. While making the calculation the arithmetic mean on the found values, it is possible to identify 69,127,615 m^3 in El Niño periods, 74,218,752 m^3 in La Niña period, and 71,654,607 m^3 in normal periods. The values found for the seasons in which had the presence of El Niño are lower than the values found for normal periods, and during La Niña periods those values are even lower and smaller than in the normal periods. It is possible to verify though the values of the volumes found, that there is sediment deposition during the dry season and erosion during the flood period. In normal periods, an intermediated volume between these extremes was found. Such comments are based in the flow data measured in the channel since the discharge of fresh water is the main control of the sediment volume in the lower portion of the estuary.

The values achieved by the discharge of freshwater vary from 700 m^3 s^{-1} during periods of prolonged drought (from the end of December to March) reaching values of 3,000 m^3 s^{-1} during the spring (September up to the beginning of December). In periods of floods in the drainage basin, the discharge of freshwater reaches values higher than 4,000 m^3s^{-1}, with the annual average of 2,000 m^3s^{-1}. In 1941, during the great flood, flow values measured in the inlet reached 20,000 m^3s^{-1}. (MOTTA,1969) The volume of sediment that were moved during the construction period of the jetties was of 12 million cubic meters, moving the nucleus of BRG toward the sea (MOTTA,1969).

The periods in which the El Niño phenomenon happens in the south of Brazil are marked by the intensification of rains that cause the outflow of the drainage basin at Patos Lagoon. North, N-NE, NE and E-NE, blow in the direction of the length of the Northern Channel, boosting the waters of the Lagoon to the channel, raising the level of the incoming section of the channel. The NE winds entail double favorable effect on the outflow of the ebb: they raise the level of water in the incoming section of the Northern Channel and reduce the level of the sea. In the period in which the meteorological phenomenon La Niña happens, shortages and great droughts during intense abnormally dry weather are very common. S-SW, SW and SW-W winds generate flood's inflow, reducing the Northern Channel level and raising the level of the sea.

CONCLUSION

The analysis of the variation of the coastline shows that the construction of the jetties has changed the geomorphology of the system of BRG, causing a great accretion in the coastline to the south of the structure and a small increase to the north, close to the base of the jetty. According to such information, it is possible to perceive the predominance of coastal transportation from southwest to northeast in the sector of the coast of RS.

The implantation of the jetties to fixate the passing over the bar entailed morphological changes, especially in the eastern spit. Such changes reflect changes in the hydrodynamic patterns, which might be associated with the construction of the structures which have become barriers for the littoral drift and caused the amplification and change in the direction of the flood currents.

The values found for the volumes between the jetties and on the nucleus of BRG during the analyzed period demonstrate the mobile characteristic of the BRG, which suffers a continuous morphodynamic adjustment. The annual variations of volume are very sensitive in relation to the annual variability of hydrodynamic agents represented by ebb currents and undulatory movements responsible for the input and withdrawal of sediment of the system.

According to the performed calculation and the found values, it was possible to perceive that these meteorological phenomenon El Niño in 1941 and La Niña in 1917, have influenced respectively in the decrease and increase of the volume of sediment deposited at the end of the Northern Channel and the BRG.

LITERATURE CITED

CALLIARI, L. J. 1980. Aspectos Sedimentológicos e Ambientais na Região Estuarial da Laguna dos Patos. Porto Alegre.RS: Universidade Federal do Rio Grande do Sul. .Dissertação de Mestrado em Geociências.

LÉLIS, R.J.F., CALLIARI, L. J. .2004 . Historical Shoreline Changes Near Lagoonal and River Stabilized Inlets in Rio Grande do Sul State, Southern Brazil. *Journal of Coastal Research*, SI 39. p301-305.

MITÁSOVÁ, H., MITÁS, L. 1993. Interpolation by Regularized Spline with Tension: I. Theory and Implementation. *Mathematical Geology*, Vol. 25, No.6. New York. USA. p641-655

MOTTA,V.F. 1969. Relatório-Diagnóstico sobre a melhoria e aprofundamento do acesso pela Barra de Rio Grande ao DEPREC.Porto Alegre, RS: IPH, Universidade Federal do Rio Grande do Sul. 114p.

PITOMBEIRA, E.S. 1975. Estimativa do Volume Anual de Transporte Litorâneo na Costa do Rio Grande do Sul. PortoAlegre, RS: Universidade Federal do Rio Grande do Sul. Dissertação de Mestrado. 110p.

VASSÃO, C.M. 1959. Planta da Barra do Rio Grande. Anos de 1883 a 1956 e 1814,1849, 1866, 1875 e 1881, do Ministério da Viação e Obras Públicas do Departamento Nacional de Portos Rios e Canais – 18° distrito de Rio grande – DEPREC. Rio Grande.