GEOACTA, 26, 71-80, 2001

SEDIMENT TRANSPORT INFERRED BY SUBMARINE BEDFORMS

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ABSTRACT

By means of bathymetric and side scan sonar records, the net circulation of sediments caused by tidal currents and waves in the outer Principal Channel of Bahía Blanca Estuary is inferred. On the northern coast of the studied area there are two harbours, Belgrano and Rosales, which are simultaneously affected by internal and external hydrosedimentological processes. Through this study, present and potential negative interactions between human activities and natural processes within the studied area are demonstrated.
Keywords: subaqeous dunes, bedload, side scan sonar, Bahía Blanca Estuary.

RESUMEN

A través del análisis de registros batimétricos y de sonar de barrido lateral se infiere la circulación neta de sedimentos causada por olas y mareas en el sector externo del Canal Principal del estuario de Bahía Blanca. Sobre la costa norte del área de estudio se encuentran dos puertos, Puerto Belgrano y Puerto Rosales, los cuales son simultáneamente afectados por procesos hidrosedimentológicos internos y externos al estuario. Por medio de este estudio se evidencian las interacciones negativas, presentes y futuras, entre las actividades humanas y los procesos naturales.
Palabras claves: dunas submarinas, carga de fondo, sonar lateral, estuario de Bahía Blanca.

1. INTRODUCTION

Bahía Blanca Estuary on the Atlantic coast of Argentina is a mesotidal estuary constituted by a 3,000 km^2 complex of channels that cross extensive islands and tidal mud flats. The interaction of tidal currents with the sediments gives an intricate environment that is permanently evolving (Gómez and Perillo, 1992, 1995; Cuadrado and Perillo, 1997). Also, Bahía Blanca Estuary has great economic importance to Argentina, since one of the most important harbour systems of the country is placed there. The Principal Channel is the main waterway to access to this system and has to be in optimal conditions to guarantee the navigation of large cargo vessels.

Therefore, many human activities such as dredging, construction of harbours, hard coast protection, jetting and landfill, are carried out to improve the economic condition of the region. However, these activities can alter the inlet geometry and hydrodynamic regime and consequently, the sedimentological and geomorphological interactions with the environment. In turn, these transformations can also provoke harmful impact on coastal water quality, biota and on various human activities in the estuary and on the adjacent coastal zone. Hence, improving studies to forecast undesirable consequences are evidently necessary.

Recibido 14-09-01. Aceptado 04-12-01

The first step to define the dynamic of the area is to know carefully its hydrography. The general bathymetry, the sedimentary characteristic of the bottom, the tidal currents and the main bedforms give indispensable information for oceanographers, who try to characterize, regionally and locally, the processes involved, the evolution and the maintenance of the sedimentary deposits.

Several studies have been done on the gross patterns of sedimentation and erosion within the Principal Channel of the estuary (Perillo and Sequeira, 1989; Perillo and Cuadrado, 1991; Gómez and Perillo, 1991). They were done in both the internal and the external zone of the estuary, whereas the intermediate zone was barely studied.

The global objective of this study carried out in the Belgrano-Rosales area, was to determine the involved factors in sediment stability in order to prevent, or at least to diminish, negative interactions between the environment and economic interests. The present study is focused on seabed characteristics because these features usually indicate the net directions of sediment transport as bed load. The knowledge of these directions of net sediment transport makes the optimization of dredging works possible.

2. STUDY AREA

The study area comprises a sector of the Principal Channel centered at 62°05'West Longitude and 38°55'South Latitude in a surface of 88 km^2 approximately. It includes Belgrano and Rosales Ports that are located on the northern coast of the outer reach of the Principal Channel, and El Embudo Channel outflow on the southern coast (figure 1). Because of their external location, internal estuarine processes and storms (mainly from the SE) simultaneously affect the Belgrano-Rosales area. The portion of the Principal Channel, where the Rosales and Belgrano access channels outflow, has the advantage of having natural depths greater than 20 m below the Datum Plane, then dredging of this area is unnecessary. However, the Principal Channel northwards the study zone, and also the access channels and the mooring sites of both harbors need to be dredged periodically in order to allow navigation.

Rosales is a civilian port that historically remains, most of the time, non operative due to excessively high siltation rates (Gómez *et al.*, 1994, 1997; Cuadrado *et al.*, 1996, Melo *et al.*, 1997). Belgrano Port, which is the most important naval base of Argentina, has recently started to exhibit similar problems (Cuadrado *et al.*, 2000). A disposal site was built in the intertidal zone located between Rosales and Belgrano Ports in order to settle the material dredged from the mooring sites of Belgrano Port. At present, the sandy fence of the disposal site was broken and the material it contained was spread over the adjacent tidal flats.

El Embudo Channel is located on the southern coast. Northwest its mouth, and very close to the coast, a longitudinal submarine sandbank parallel to the coast is placed. There is a narrow channel situated between the submarine sandbank and the coast which has a maximum depth of 14 m. However, this channel is not used for navigation because its depth diminishes westwards, ending in a sill only 5 m deep where the submarine bank meets the coast. This channel is used as disposal site for the sediments dredged at the access channel of Belgrano Port (100,000 m^3/yr). Also the materials dredged from a portion of the Principal Channel (80,000 m^3/yr) are dumped there.

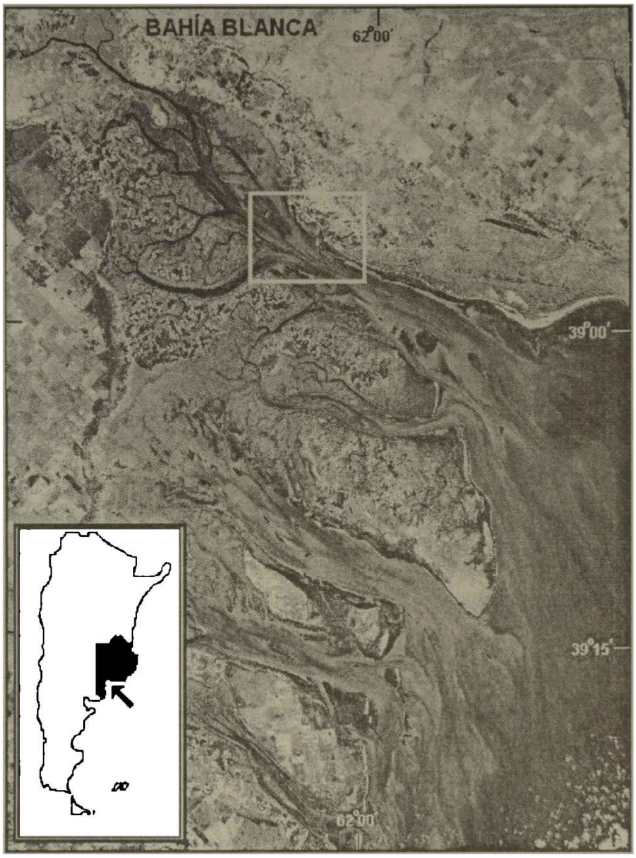

Figure 1. Satellite imagen of Bahía Blanca Estuary showing the location of the study area.

3. METHODOLOGY

To define the geomorphologic characteristics of the studied area, several bathymetric and side scan sonar surveys were carried out from 1998 to 2000. Bathymetric profiles were taken using a 208 kHz Raytheon echosounder, and an EG&G SMS960 (105 kHz) side scan sonar was also employed. Both are acoustic systems that initiate the propagation of sound pulses in the water and measure the lapsed time between the initiation of the pulse and the arrival of return signals reflected or backscattered, from the target features on the sea floor.

By means of a side scan sonar it is possible to observe bottom characteristics of the seabed as it gives a vertical projection of sediments and topography in a way that resembles an aerial photography. It provides an image of the distribution of sediment, bedforms, and larger features as shoals and channels. The echo sounder gives a profile of the bottom. Through both instruments it is possible to obtain a 3D representation of seabed features and to determine changes in sediment characteristics of channels, which thus be helpful in mapping directions of sediment transport (Morang *et al.*, 1997).

Side scan sonographs were collected along a total of six tracklines in the Principal Channel scanned 100 m to each side of the track of the ship. The side-scan sonar and the echosounder were used simultaneously because one tool complements the other during interpretation.

A GPS operating differentially was used as navigation system, with an error in the order of 1 m. All bathymetric tracks were made crossing the area in the direction of maximum morphological variation with a spacing between 300 to 100 m, depending on the bottom variability. Bathymetric data were corrected to the Datum Plane employing tidal records gathered at Belgrano Port tidal gauge. During surveys, side scan sonar information was digitally recorded and then reproduced and scale-corrected later at the office.

To study the seabed sediments a total of 45 bottom samples were acquired within the study area by means of a Dietz-Lafond grab sampler. Sediment samples were processed following usual laboratory procedures for grain-size analysis as described by Folk (1974).

4. RESULTS

The bathymetric map (figure 2) shows the geomorphologic characteristics of the study area. The Principal Channel here has a mean width of 3.2 km. Depths range varies from 10 m near the flanks up to 21 m in the middle of the channel. Maximum flank slopes (3%) are found at the northern coast eastwards Rosales Port, decreasing towards Belgrano Port area reaching values of the order of 1%. The southern channel flank slope is variable with a mean value of 0.8%.

The Belgrano Port access channel, 3 km long, reaches maximum depths of 10 m. This sector has to be dredged as well as the Rosales Port access channel whose length is less than 1 km and whose maximum depths come up to 5 m. El Embudo Channel reaches maximum depths of 8 m, diminishing to 5 m at its mouth.

Sediments at the studied area have a wide range of grain size distribution, from coarse sand to medium silt (1 to 5.5 phi, figure 3). The coarser sediment is mainly found at deeper sectors, while the finer sediment is located in the shallow areas. On the southern coast as well as in the intertidal zone of the northern coast of the Principal Channel there are outcrops corresponding to ancient tidal flats. Then, the samples obtained there correspond to medium to fine sand having a high percentage of clay (33%). Present erosive processes are affecting these sediments exposing a hard bottom. As their grain size distributions do not reflect present dynamic conditions they were not included in the figure.

Four characteristic sonograph patterns were used (figures 4-7) in conjunction with the textural and supplemental marine-geologic data to identify and map the sedimentary areas within the study area. From the disposition of bedforms it is possible to infer the direction of net sediment transport as bed load (non-cohesive sediments).

Darker tones in the sonograph indicate areas that produced stronger backscatter (relatively coarse-grained sediments or pattern of areas of erosion or non-deposition), whereas lighter tones indicate areas that produced weaker backscatter. The intensity of the reflected signal is a function of material properties as well as of relief.

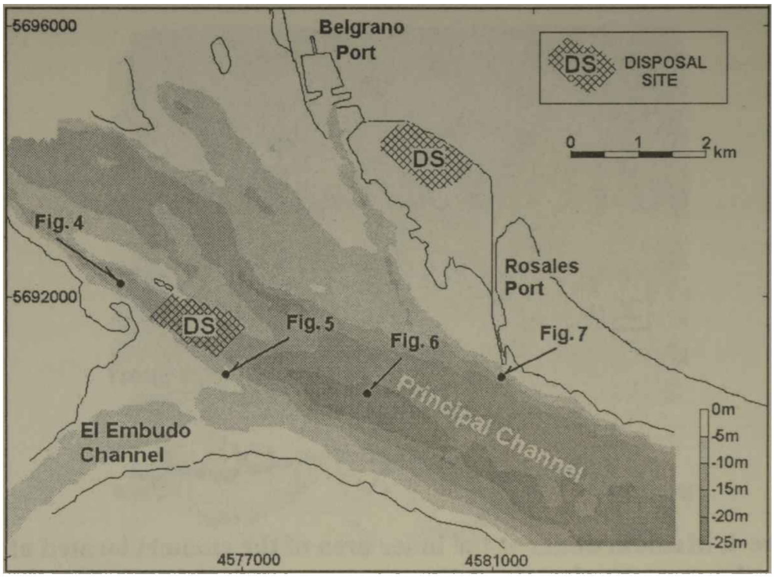

Figure 2. Bathymetric map of the study area. Locations of side scan sonar examples presented here are also shown.

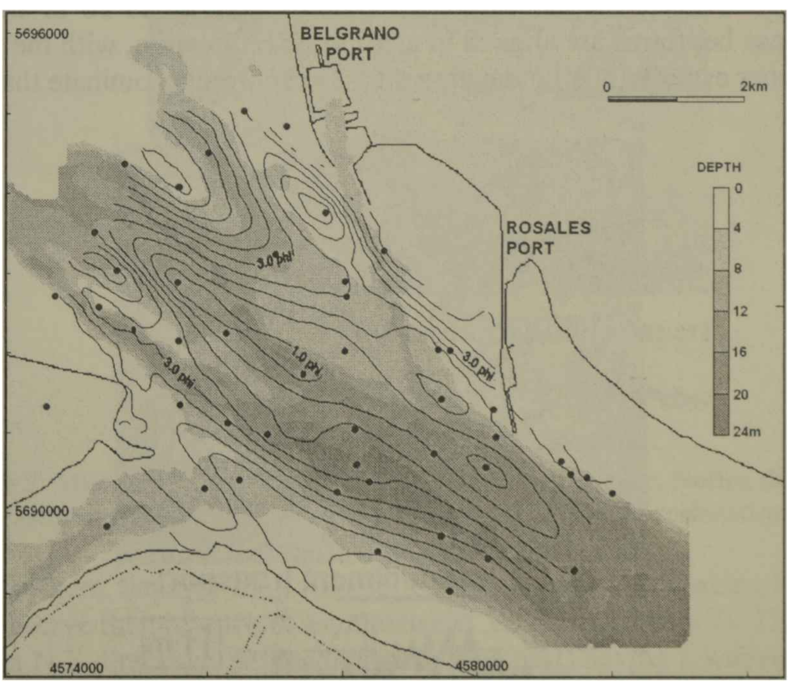

Figure 3. Mean grain size (phi scale) of bottom sediment samples. Contour interval is 0.5 phi.

Sediment transport inferred by submarine bedforms.

The bottom of the internal portion of the channel located between the submarine bank and the southern coast is covered with flood oriented 3D medium dunes (classification according to Ashley, 1990) with a wavelength up to 8 m. Crests of these dunes are aligned in N-S direction with a height of 1 m (figure 4). They are composed of fine sand ($D_{50} = 2.6$ phi).

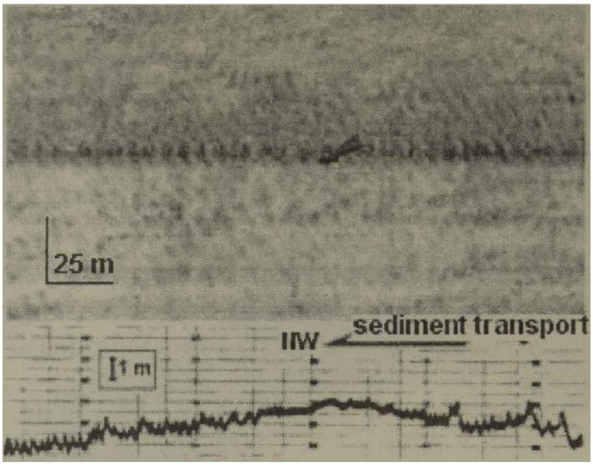

Figure 4. Medium dunes at the inner area of the channel located at the south coast, showing the sediment transport to the inner estuary.

The external sector of this channel is covered with coarser sand ($D_{50} = 1.9$ phi) conforming asymmetrical large dunes with a wavelength up to 10 m and 1 m high (figure 5). These bedforms are aligned in a NNW-SSE direction, with the lee oriented towards the inner estuary (NW) indicating that flood currents dominate this channel.

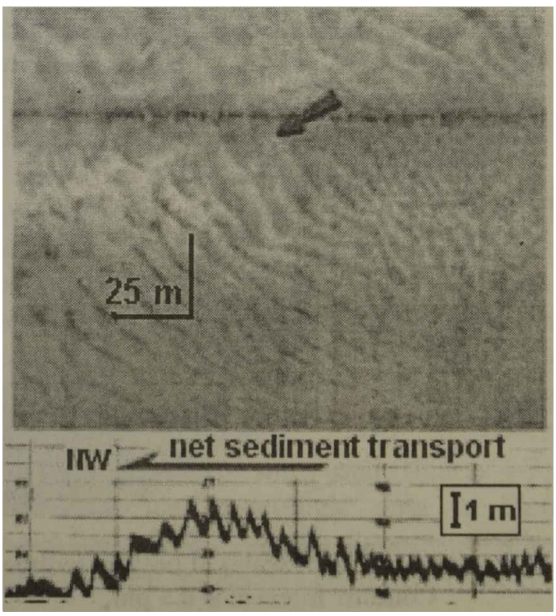

Figure 5. Large dunes in the outer area of the channel located on the south coast.

In the Principal Channel, where depths are greater than 20 m, there are well-developed very large dunes in medium sand (D_{50}= 1.6 phi) with a height of 4.5 m (figure 6). It is possible to observe that the stoss side of the dunes is covered with medium dunes conforming fan-like structures, which are provoked by the separation of the flow after crossing the crest (Aliotta and Perillo, 1987).

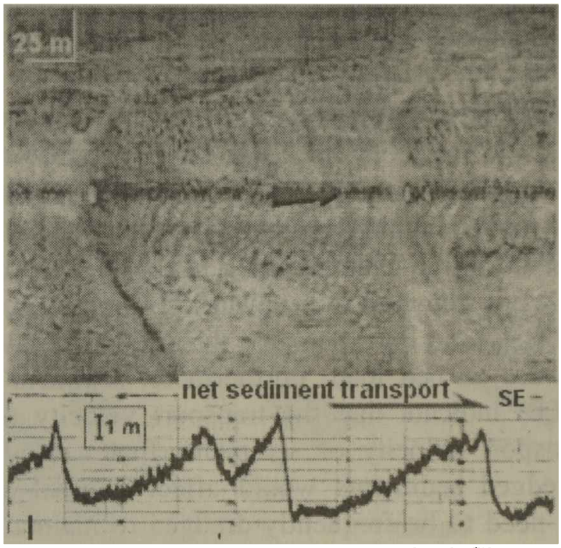

Figure 6. Very large dunes located in the Principal Channel at 20 m depth.

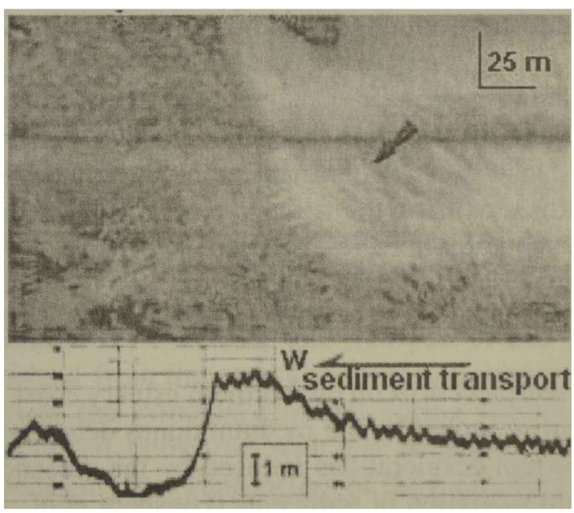

Figure 7. Medium dunes located at Rosales Port stone pier. Notice the change in bottom characteristics at West due to ebb currents acceleration.

At the northern flank of the Principal Channel, eastward Rosales Port pier, it is possible to observe the presence of asymmetrical 3D dunes (figure 7). These bedforms are aligned in N-S direction (perpendicular to the coast) having a wavelength ranging from 8 to 18 m and heights of the order of 1 m. The sediment where the bedforms are built is D_{50} = 2.6 phi. These bedforms have their lee oriented westward, indicating a net sand transport to the inner estuary, inversely to what occurs at the central portion of the channel. A darker gray background reflection on the left side of the sonograph indicates a featureless area, probably composed by highly compacted or lithified sediments (figure 7). This clear difference in bottom characteristics would be related to changes in the dynamic conditions of the area. The bedforms ends abruptly westward the pier, coincident with a deepening in 3.5 m as is shown by the echosounder record.

5. DISCUSSION AND CONCLUSIONS

Both, bedforms and sedimentological characteristics are used to define the dynamic conditions in the Belgrano-Rosales area in the Principal Channel. According to the bedforms observed in the channel adjacent to the south coast, near El Embudo Channel, the net sediment transport is headward. Therefore, sediments dredged from the access channel of Belgrano Port that were disposed here have large possibilities of migrating northwestward as bed load. Furthermore, sediment transport calculations (Ginsberg *et al.*, 2000) indicate that the transport velocity of disposal material is greater than the transport velocity of sediments that naturally occur in the area. Eventually, these dredged sediments would affect internal areas of the Principal Channel that already need to be frequently dredged to maintain navigational depths. The use of this submarine channel as a disposal site has in fact the serious hazard of increasing the total amount of sediments that should be dredged from the internal estuary areas. Consequently, more studies in a larger zone (including internal areas) have to be done.

On the other hand, the northern estuary coast, where Belgrano and Rosales Ports are located, is particularly affected by waves locally generated by southern and southeastern winds. This area is also influenced by those oceanic generated waves that can enter through the mouth of the estuary (NEDECO-Arconsult, 1983). As these waves obliquely attack the shore, a westward sediment drift is generated on the northern coast (Gomez *et al.*, 1994, Melo *et al.*, 1997), acting Rosales Port as an obstacle where the sediment drift is trapped (Gomez *et al.*, 1997, Cuadrado *et al.*, 1996)

Such westward sediment drift on the northern estuary coast is also present in zones deeper than 8 m, as it is shown by the medium dunes determined by side scan sonar. However, the ebb current accelerations induced by the presence of Rosales Port pier interrupt the westward migration of sediments (Ginsberg *et al.*, 2001). Then, it is clear that the presence of the pier act as a barrier preventing sediments coming from the external estuary area to reach the access channel of Belgrano Port. The longshore currents induced by waves are still present westward the pier, but with an available amount of sediment almost insignificant to be transported as bedload.

The fine sediments dredged from the mooring sites of Belgrano Port and located in the intertidal area between Belgrano and Rosales ports are being spread over the adjacent tidal plains due to the broken fence. The waves (mainly during storm periods) were responsible for the rupture of the defense and the sediment that was held into the disposal site fed the longshore currents towards the inner estuary. Since the rupture of the fence the most internal area of the access channel of Belgrano Port started to experience an abnormally high siltation rate.

Due to the asymmetry of the large dunes developed in the deeper sector in the Principal Channel, the sediment is transported towards the mouth of the channel. These large dunes imply that large volume of sediment is being transported.

On the basis of the transport inferred from the asymmetric bedforms, the net sediment circulation in the entire studied area is qualitatively schematized on figure 8. These are preliminary results that need further analysis to confirm the described facts, using currentmeters measurements to ascertain the current velocity and direction. Besides, in order to detect the rate of migration of the dunes, several successive scan sonar surveys need to be done and compared.

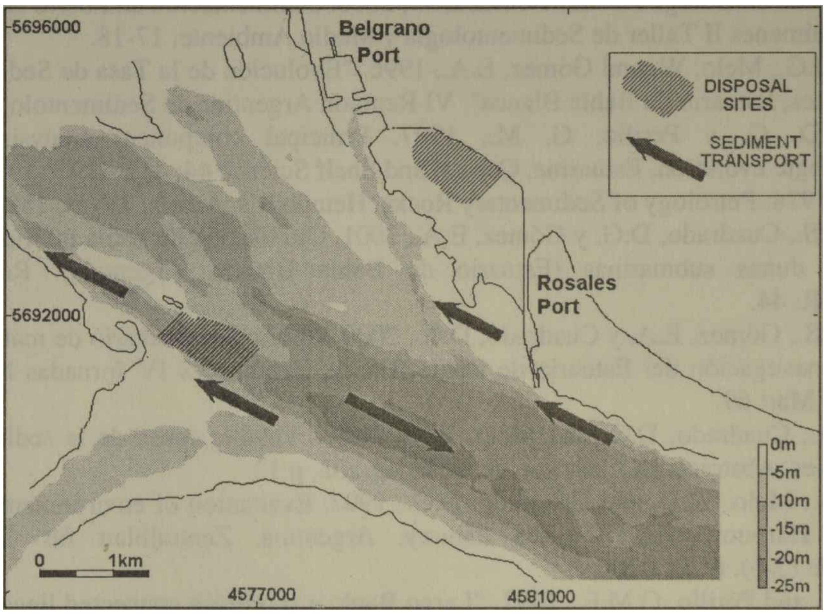

Figure 8. Scheme of bed load net sediment circulation in the study area.

According to the directions of net sediment transport as bed load, we suggest to locate the sediments dredged from the access channel and mooring sites of Belgrano Port at the deeper areas of the Principal Channel during ebb periods. The dredged volume is almost insignificant compared with the deepness and the width of the channel as it will represent only few centimeters of the total channel depth. In fact, if the 180,000 m^3 of sediment budget were disposed over a 2 km^2 area, it would represent only 9 cm in depth reduction. As it can be seen at the deepest parts of the Principal Channel (figure 6) the important dunes that occur there indicate a strong sediment transport towards the estuary mouth. Then, probabilities for the sediments located here to affect negatively any other navigable sector would be almost null.

Acknowledgements: Funds for this study have been provided by a grant PICT N° 07-03955 from the Agencia Nacional para la Promoción Científica y Tecnológica (ANPCyT), and partially funded from grants of CONICET (PEI N° 438, 440 and 460) and UNS (PGI 24/ZH08). The authors express their thanks to the crew of the R/V Buen Día Señor for the assistance provided during the field cruises. A. Raniolo, A. Echevarría, C. Galán, L. Kaufman, Lic. J. Spagnuolo, Lic. W. Melo and R. Zibecchi were very helpful in the field works, as well as to H. Pellegrini and J. Colombani for samples processing.

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