Littoral Drift, Evolution and Management in Punta Médanos, Argentina

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ABSTRACT


This study examines the relation between landforms and coastal dynamics; the existence of a compound spit and the prevailing sea wave direction that originated it are established. From the angle of incidence of the waves along the coastline, a formula is presented to determine the direction of growth of the spit. A relative quantification of the littoral drift is determined including different cases of possible evolution of the coastline; proper consideration is given to the incidence of the wave trains. The permanence of the present hydrodynamic model over the last 6,000 years is also established. The hydrodynamic stability of the sector between Punta Médanos and Punta Rasa is conditioned upon various climatic changes. Finally, a strategy to avoid erosion of the coastline between Punta Médanos and Punta Rasa is suggested: (a.) artificial nourishment of the beach with materials that are not included in the present littoral dynamic, and (b.) the correction of construction areas on the dune ridge.

ADDITIONAL INDEX WORDS: Argentina, climatic change; coastal evolution; littoral drift, management.

INTRODUCTION

Along the coastal area between Punta Médanos and Punta Rasa, Argentina, are seaside resorts crowded with tourists in summer. This is due to the proximity of highly populated, urban centres like Greater Buenos Aires (population about 10 million people, situated some 300 km from the resorts). In these resorts, there are a large number of buildings for recreation, dwelling and commercial activities. Recently, the buildings situated near the shoreline have suffered damage, quite serious in some cases. Consequently, the community demanded engineering structures to protect their property. Random projects began quickly; instead of solving this serious problem, some properties were lost and others remain in serious danger.

PARKER et al. (1978) studied the linear shoals in the inner continental shelf of the area situated seaward of Punta Médanos (Figure 1). LÓPEZ (1993) worked on land and carried out systematic and thorough research of the beach profiles of the area between Punta Médanos and Punta Rasa. Furthermore, in a report for the town council, CODIGNOTTO (1993) divided the area into sectors of accumulation and erosion, finding accretion in Punta Médanos and Punta Rasa. The rest of the sectors proved to be erosion zones to different degrees. CODIGNOTTO (1993) pointed out that the causes of the erosion were anthropogenic, as the construction industry takes sand from the beach and the dune. Consequently, it was concluded by CODIGNOTTO (1993) that the area was eroding due to bad management of the coastal zone, and that the construction of “protective” structures could spread the erosion.

Control carried out by authorities has been deficient and careless in some cases. Therefore, it would be dangerous to proceed with a plan to alter the dynamics of the coastal system, without thorough research to guarantee the success of the changes to be performed.

This study outlines the general principles of littoral drift and coastal dynamics. Its aim is to provide an integral model of coastal circulation and prove that any alteration of the environment will bring about an alteration in area hydrodynamics; this knowledge will provide a basis upon which to plan possible future restoration and will preclude plans that could aggravate the present problems.

Following these criteria, it is important to predict coastal behaviour under several possible hydrodynamic situations, to avoid possible damage caused by inadequate management of the coastal environment and to reduce environmental impact.

Area Studied

The area studied is situated in the northeast section of the province of Buenos Aires (Figure 1), and forms parts of the geological province called Cuenca del Saladillo (BRACACCI, 1972) and the geomorphological province known as Pampa Degrimida (FRENCHETTI, 1950). Different Quaternary formations constitute the subsoil and surface of the studied area.

The Pleistocene sediments crop out in the area and consist of continental sediments, composed of clayey silt and partially sandy, brown-yellowish colored great mammiferous re-
Coastal Management in Argentina

This work is part of an integral study of geology, dynamics and coastal handling done by personnel of CONICET and the University of Buenos Aires; various field works were fulfilled. We have studied the geomorphology and hydrodynamics of an area of the coast of Buenos Aires with two different purposes: a.) prediction of the evolution of the coastal outline under different possible situations, caused by the incidence of the wave train on the coastline, and b.) reconstruction of the dynamics which generated the cited outline, applying the same methodology used in Peninsula Valdés and Bahía San Sebastián by KOKOT et al. (1988).

The former purpose involves analyzing the evolution of an area of coast called the "initial coastal outline". For its study, satellite images, aerial photographs and maps were used to establish the geometric relation between the studied landforms, e.g., the angles between the beach crests and the coastline and the angle between strike spit and the direction of the coast from which the sediments that compose it come.

The coastal outline was affected through refraction by the action of waves and currents, resulting in an area of littoral transports that may be either under erosion or accretion, or liable to dynamic equilibrium; the result is a coastal outline that we will call consequent or final where stable or unstable landforms exist, depending on the acting dynamics. To analyze the evolution of the coastal outline for a wave train that incises with a certain angle, it is possible to divide this outline into segments of coast and to make a relative quantification of the littoral transport in each segment.

For this analysis, some concepts should be reviewed. When referring to littoral transport, ZENKOVICH (1967) defines "longshore flow" as the movement of the mass of material carried along the beach and the offshore by the action of the waves and currents. When appraising the flow of material, he considers its "capacity" as the maximum amount of material that the currents and waves are able to transport along a given coastal area in a given amount of time. This flow depends on the energy and direction of the waves that approach the coast anywhere in the offshore. At a constant energy, the maximum capacity corresponds to the one that results when the passing of the waves forms an angle \( \Phi \) with the coastline. Increase or decrease in the value of this angle implies decrease in capacity. The study of the average flow capacity for a long period requires the energy of the wave rate, and its direction. According to ZENKOVICH (1967), LONGUET-HIGGINS (1970) and KOMAR (1976), the value of \( \Phi \) is 45°; this value corresponds with the maximum of the functions used by these authors. If we consider that the maximum transport takes place when \( \alpha = 45° \), we can then establish a...
Table 1. Relative littoral drift related to prevailing sea wave direction.

<table>
<thead>
<tr>
<th>Littoral drift vector (adimensional value)</th>
<th>Angle of incidence (grades)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>45.00</td>
</tr>
<tr>
<td>9</td>
<td>32.08</td>
</tr>
<tr>
<td>8</td>
<td>26.56</td>
</tr>
<tr>
<td>7</td>
<td>22.21</td>
</tr>
<tr>
<td>6</td>
<td>18.43</td>
</tr>
<tr>
<td>5</td>
<td>15.00</td>
</tr>
<tr>
<td>4</td>
<td>11.78</td>
</tr>
<tr>
<td>3</td>
<td>8.79</td>
</tr>
<tr>
<td>2</td>
<td>5.77</td>
</tr>
<tr>
<td>1</td>
<td>2.87</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

The direction of the coast where the sediments that compose it, come from.

If a spit grows following the direction of sediment transport, i.e., from $\alpha \leq 45^\circ$, this is then a case in which $\alpha > 45^\circ$ as the spit progrades in a different direction. The spit will then be oriented in such a direction that the flow capacities in both areas where the waves incise are equal.

The two directions with equal capacity of littoral transport are shown in Figure 3, and its values can be checked in Figure 2. From Figure 3, we get:

$$2(\alpha - 45^\circ) = \Omega \quad \Rightarrow \quad \Omega = 2\alpha - 90^\circ \quad (1),$$

for $\alpha$ different from $90^\circ$ and $\alpha > 45^\circ$, being $\alpha =$ angle of incidence of the perpendicular to the wave train in respect to the coastline, and $\Omega =$ angle that the direction of the coastline forms with the resulting spit.

This formula enables us to calculate the angle of growth of a spit, if the angle of incidence of the wave train on the coastline is known.

As we know, the value $\Omega = 36^\circ$ (obtained by measuring in satellite images and aerial photographs, Figure 1), and from (1) we get:

$$\alpha = (\Omega + 90^\circ)/2 \quad \Rightarrow \quad \alpha = 63^\circ \quad (2)$$

corresponds to the angle of incidence of the orthogonal to the prevailing wave train (this direction corresponds to an azimuth = $331^\circ$) in the area of Pinamar and Villa Gesell, validating the general estimation done by Lanfredi and Salvador (1978), according to Parker et al. (1978). This drift condition and littoral transport in the segments of coast analyzed is the statistics or resultant, verified by the existing landforms, and does not indicate a lack of knowledge concerning the multiple directions of wave incidence on this coastline. This confirms that the hydrodynamic conditions have persisted over the last 6,000 years, approximately; this is the age of the landforms involved, according to Codignotto and Aguirre (1993).

Any change in the angle of incidence of the wave trains will bring about a change in the conditions and the corresponding variation in the erosion-accretion system. The rebuilding of the dynamic conditions that originated the configuration of today's coastline was obtained in this manner. In the following steps, the evolution of the coastline under different possible wave incidences, is predicted. We can study the follow-

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ing cases (Figure 4) in which the orthogonal to the wave train that incises on the coastline is indicated by a geographical azimuth value and the littoral drift vector by a "quantified littoral drift" value taken from Figure 2.

In this study, the stretch of coast between Punta Médanos and Punta Rasa will be called North Sector, and the one between Villa Gesell and Punta Médanos, South Sector. For the purpose of this study, the coastline was divided into segments where the waves incise with a different angle; therefore, the littoral drift vector has different values. Passing from a higher to a lower value when relatively quantifying these vectors means that there is accretion in the second sector, whereas passing from a lower to a higher value means there is erosion in that sector.

Angle of Incidence of the Waves and its Effects on the Coast

Ten different cases are studied, covering different possibilities in the stretch of coast analyzed.

(1) Incidence of waves, azimuth = 358° shows littoral drift in the South and absence of littoral drift in the North; the waves do not incise on this segment of coast. The result is an accretion in Punta Médanos with a tendency to form a spit following the direction of the South sector. These deposits agree with the submerged deposits mentioned by PARKER et al. (1978). Erosion in the South Sector depends on the material supply coming from places situated to the South of the studied area. If the supply is insufficient as per the flow capacity, the South Sector will erode; if the supply is enough, the area will behave as a sector of transport in dynamic equilibrium with the environment.

(2) In the Azimuth between 34° and 178°, no littoral transport is recorded due to the lack of incidence of waves on the coastline.

(3) The incidence of waves between Azimuth 178° and 214°. Littoral drift is recorded in the North towards the South, and no drift is recorded in the South Sector. Consequently, a spit tends to form in Punta Médanos following the direction of the coastline at the expense of erosion in the North Sector. This situation, Azimuth 214° is illustrated.

(4) Between 214° and 223°, littoral drift increases in both areas until reaching a maximum (littoral drift vector = 10) in the North. Erosion is recorded in the North and a spit is likely to form in this direction in Punta Médanos. There would be erosion in the South Sector if the material was deposited in Punta Médanos. The situation Az 223° is illustrated.

(5) Between 223° and 241°, erosion is recorded in the North and a spit is likely to form in Punta Médanos, veering from the direction of the coastline. The possible directions of growth of the spit are illustrated and it is valued according to Azimuth 241°.

(6) Between 241° and 268°, erosion in the South increases and decreases in the North. Lack of littoral drift in the North and erosion in the South are illustrated as from Punta Médanos.

(7) From 268° up to 304°, drift decreases in the South and increases in the North. Flow directions are opposite and there would be erosion as from Punta Médanos. Lack of drift in the South and littoral drift in the North is illustrated.

(8) Between 304° and 313°, the drift increases in both areas and reaches a maximum in the North sector; the angle of incidence is 313°, according to the illustration. As a consequence, there would be erosion in the North sector and transport in equilibrium in the South sector, provided the flow gets to this saturated area. If not, there would be erosion.

(9) Between 313° and 331°, the drift increases in the South and decreases in the North, until both drifts become equal as illustrated. This situation is resultant in present spit with a distal expression represented by Punta Rasa.

(10) Between 321° and 349°, the drift increases in the South and decreases in the North. The consequence of this drift would be the construction of spits in positions that vary from that direction in the Southern area. Situation 334° is illustrated.

Figure 3. Angle of growth of a spit, knowing the angle of incidence of the wave train.
Between 349° and 358°, the drift varies in the Southern area and decreases in the North until disappearing, illustrated in Diagram 1, Figure 4.

**DISCUSSION**

Analyzing the above mentioned cases, we conclude that the Northern sector is naturally under accretion and would erode if material supply coming from the South stopped. It could also erode if the prevailing waves attack the coast with an angle of incidence higher than present due to a climatic change. Barros and Bischoff (in Arias, 1994) suggest a differential heating in the Atlantic Ocean with the subsequent multiplication of the habitual potency of the anticyclone, increasing the frequency of winds from the southeast. This change of potency may come accompanied with a change of the direction of the waves and present a situation similar to that given in Example 8 of Figure 4; the hydrodynamic conditions are unfavorable for the North sector of the studied coast, passing from a situation of accretion to another of erosion with a small change in wave incidences toward the south. If the angle of attack changes towards the North, the result would be an increase of erosion in the south and an accretion in the north, with a change of direction in the growth of the spit.

There are several places of erosion in the North; according to Codignotto (1993), this is due to bad management or provoked erosion by anthropic action. Sand is taken from the coastline (beach and dune) for construction purposes. On top of this, there exists demographical pressure and high competition to build in the riparian area which is highly profitable for tourism.

To solve this problem, strengthening of the dune line through construction of dikes, sea walls or retaining walls will be necessary. Thus as is already known, more sediment from the beach will be lost, sapping of the structures will occur, and if the natural supply of sand is not enough to make up for the loss, the whole beach will be lost.

Construction of groins would also be damaging; erosion induced by these structures would aggravate the problem. Construction of piers, parallel to the coast, would have a similar effect and like groins would aggravate the problem down drift of the structures, despite encouraging accretion.

Furthermore, since the dunes that could have nourished the beaches naturally after storms have been eliminated, it is now necessary to do artificially what the system used to do naturally. If we intend to recover the beach quickly, the places involved will have to be filled with material obtained from some other place; to preserve the natural drift of the beach, this material should bear the same granulometric characteristics.

Three possible places for extraction of sand are shown in Figure 1. (a) The area situated offshore in front of Punta Mé­danos. Extraction there would mean removing material that is afterwards naturally distributed by the prevailing coastal dynamics. Consequently, erosion would occur downdrift. (b) Somewhere from the hook-shaped spit, but out of the present coastal dynamics. From the point of view of dynamics, these places would be considered acceptable as new material is supplied to the coastal flow. However, there is a drawback from the point of view of cost, as transport and cost of extraction (they are in private lands) will be expensive. (c) If material is extracted from the distal portion of the spit (Punta Rasa), the coastal dynamics would not suffer big changes as this is the “end of the trip” for the particles coming from the South. However, transport, as in the case previously cited, would increase the cost of the project. If the idea of extracting material from this area is accepted, then a study to determine the annual values of accretion would be required. This is important to determine if extraction is higher than this value, will result in erosion. As the spit has a shadow zone in Bahía Samborombón that depends on the prevailing sea wave direction, its destruction (natural or induced) in the area of Punta Rasa would bring about dramatic changes in the bay. It should be pointed out that this place is an important fauna reservation; it is the point of arrival of birds migrating from and to the Northern Hemisphere. Therefore, before making any decision, economic and social costs of the strategy must be taken into account.

This work relies on Codignotto (1993) criteria, that suggests as a first step to stop the extraction of sand on the coastline.

The second step to follow would be to nourish the affected areas artificially and, if possible, to proceed to the urban
evacuation of the coastal stretch lying next to the shoreline despite social opposition.

This generally brings about resistance and is not easily accepted; but in this case, it is the most convenient option as there are few buildings in the area. Otherwise, construction of barriers would only contribute to the destruction of this "beach resource", upon which the economic stability of this area is dependant.

CONCLUSIONS

(1) We establish the existence of a hook-shaped compound spit that progrades in such a way that does not follow the direction of the coast where the sediments that compose it, come from. The relation between the direction of growth and the acting dynamics is also established. This relation shows that the orthogonal to the wave train, statistical or resultant, that gives origin to the spit has an Azimuth value of 331°, and forms an angle of 61° with the coastline between Villa Gesell and Punta Medanos.

When we know the resulting landform namely, composed spit, like in this case, the direction of incidence of the waves can be calculated through this formula:

\[ \Omega = 2\alpha - 90° \]

Besides, when knowing the outline of the coastline and the angle of incidence of the wave train, this formula enables us to predict the direction of growth of the consequent spit.

(2) The hydrodynamic model that originated the present coastal outline has persisted throughout 6,000 years approximately.

(3) The area between Punta Medanos and Punta Rasa is naturally in accretion. Problems of erosion are due to a bad coastal management, caused by deficient urban planning and direct anthropic action on the beach-dune system when sand is removed. Recovering of the beach is possible through artificial nourishment of the damaged areas, getting the material from areas that are not involved in the present coastal dynamics, as any kind of accumulation in an area will bring about erosion in another one. The possible evacuation of areas with buildings along the ridge of dunes should be taken into account to enable its self-recovery.

(4) The hydrodynamic stability of the sector placed between Punta Medanos and Punta Rasa is conditioned to the subsistence of the climatic conditions because a slight change of the position of the wave generating centres of the South Atlantic would imply a dramatic change in the coastal outline.

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LITERATURE CITED


