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# Effect of El Niño on the subaerial beach Playas de Rosarito, B.C., Mexico

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**RESUMEN**

Las extensas playas localizadas cerca de la frontera México-E.U.A. juegan un papel importante en la economía del municipio de Playas de Rosarito, México. Durante el invierno de 1998, se observó una intensa erosión de las playas de la localidad como resultado de un régimen de oleaje muy energético asociado al evento de El Niño (ENSO) en combinación con altos niveles de marea. La severidad de estas condiciones causó inundaciones y destrucción de varias residencias ubicadas en la posplaya y las capacidades recreacionales y de protección de la playa disminuyeron significativamente. Mediante la comparación de los perfiles de playa se observó que el máximo volumen de arena removido de la playa subaérea fue de $66.9 \times 10^{-3}$ $m^3$/m/día y un retroceso promedio de la berma de 2.3 m/día. El desplazamiento máximo hacia tierra de la berma durante el período en estudio fue de 66 m. La altura del perfil final fue de hasta 3.5 m más bajo que el inicial, por lo que es posible que se requiera de un período más prolongado de oleaje bajo para que se restaure la altura del perfil inicial. Es necesario evaluar el papel que juega el dinámico depósito de grava que se observa en la parte norte del área estudiada. La importancia que tiene la playa en la economía local justifica el desarrollo de un programa observacional continuo.

**PALABRAS CLAVE:** Erosión de playas, El Niño, olas de tormenta, Baja California.

**ABSTRACT**

Extensive beaches located near the Mexico-USA border play an important role in the economy of the city of Playas de Rosarito, Mexico. Intense beach erosion occurred during the winter 1998 as a result of a very energetic wave regime associated to ENSO-El Niño event, in combination with high water levels. The severity of these conditions caused flooding and destruction of several houses on the beach. Recreational and protection capabilities of the beach were severely diminished. Profile comparison showed that maximum volume of sand removed from the subaerial beach was $66.9 \times 10^{-3}$ $m^3$/m/day with an average recession of 2.3 m/day. The maximum shoreward displacement along the study period was 66 m. The profile height was up to 3.5 m lower than the initial profile, so a long period of mild wave conditions is needed to restore the initial profile height. The role played by the highly mobile gravel deposit along the northern portion of the study area need to be assessed.

**KEY WORDS:** Beach erosion, El Niño's, storm waves, Baja California.

## INTRODUCTION

The sandy beaches of Playas de Rosarito (Rosarito), Baja California, Mexico, represent an important natural asset for the municipality. Nearly 60% of the economically active population depends on tourism generating an intense demand on the beach as a recreational resource (COPLADEM, 1996). Despite this, beach studies in the area have received very little attention and few studies in the vicinity of the water intake of the power plant "Presidente Juárez" operated by Comisión Federal de Electricidad (CFE) have been made (Marmolejo-Lara, 1985; Appendini *et al.*, 1998). The continuous construction of infrastructure near and on the beach itself, have increased its vulnerability to erosion, buildings damage and loss of property.

It has been recognized that when an El Niño-Southern Oscilation (ENSO) occurs, a very energetic wave regime is observed along the coast of California and Oregon (Seymour, 1998). As the ENSO develop, that is, as the regular easterly equatorial winds decline in strength, the warm water pilled up on the west side of the Pacific moves eastward, pulling with it the atmospheric convection centers. The effect in the atmosphere is a modification of the westerly flow of the jet stream causing the replacement of the typically high pressure over the Aleutian Islands by a low pressure region. This relocation causes the jet stream to split into two branches, one flowing in a more easterly direction while the other moves to the south over the area around the Hawai'ian Islands strengthening an atmospheric low with high winds and large west-to east fetches. The high amplitude and long period waves thus generated reach the coast of California, and eventually the cost of Oregon(Komar *et al.,* 1989), with exceptional ability to erode beaches and destroy coastal infrastructure (Seymour, 1998; Stolarzzi and Griggs, 1998).

Beach changes are not documented for most of the Baja California coast. The objective of this paper is to describe and report on beach changes during the winter of 1998 El Niño's by means of beach profiles and to emphasize the need for long term studies to improve on the beach use as a natural resource.

## STUDY AREA

Playas de Rosarito is located 25 km to the south of the Baja California-California border (Figure 1). The approximately 11 km beach from Punta Los Buenos to Punta La Paloma is only interrupted by the breakwater and groins built for the cooling system of the Presidente Juárez power plant. The adjacent beach to the north is relatively wide (100-200 m) with small dunes in the backshore; but 1.5 km to the north of the breakwater the beach narrows to about 40-60 m and bluffs replace the dunes. It is common to find a variety of seawalls at the bluff toes to protect the bluff itself and the adjacent infrastructure and property. Of particular interest are the alongshore gravel deposits that are sometimes covered by sand and sometimes conform the beach surface, and can thus become available to longshore transport; deposit dimensions are variable in time and space. Additionally, under erosive conditions, a rocky platform emerges along several beach stretches in the northern portion of the study area. To the south of the water intake, the beach is as wide as the northern beach, no dunes are present and tourism and residential infrastructure near and on the beach is most abundant.

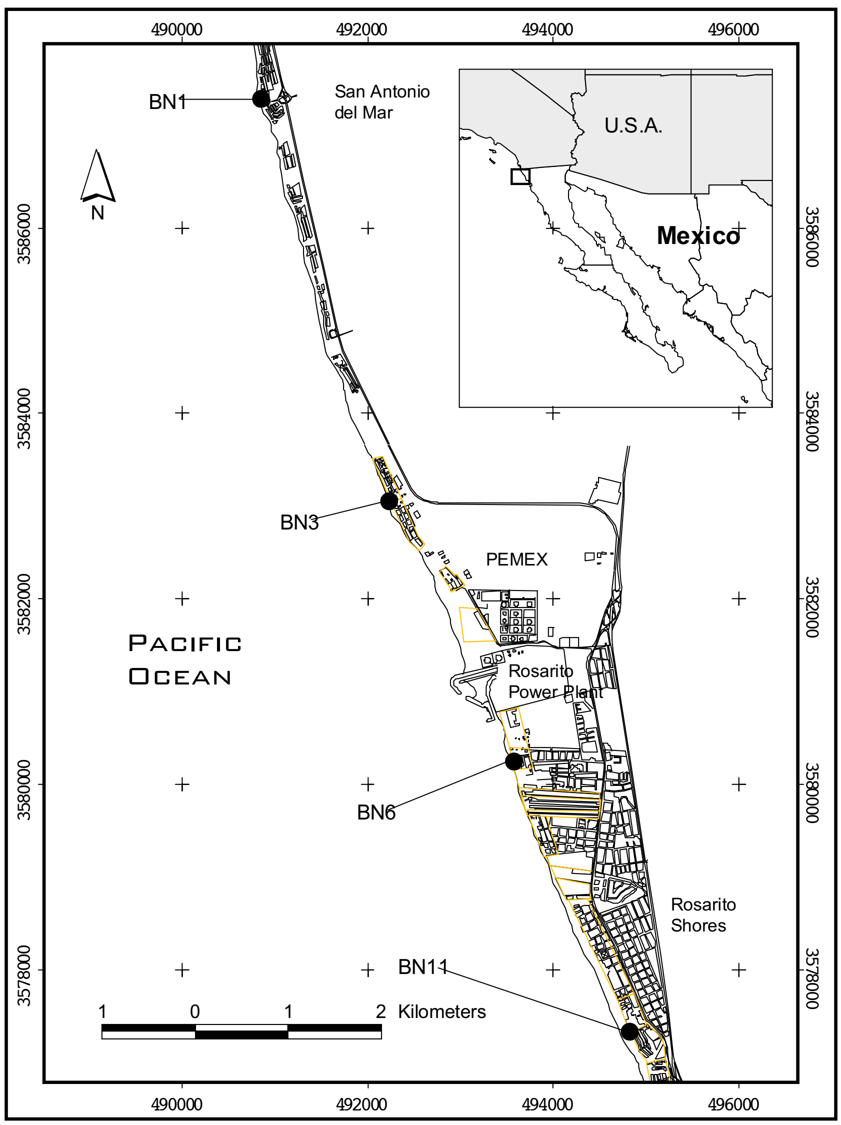


Fig. 1. The CFE's breakwater is the most significant feature in the area. The location of the four surveyed beach profiles are shown.

## METHODOLOGY

Beach profiles at San Antonio del Mar (BN1), Baja del Mar (BN3), Colonia Obrera (BN6) and Rosarito Shores (BN11) (Figure 1) were surveyed during the daylight lowest low tide on a monthly basis from June 1997 to June 1998 and fortnightly during February to April 1998. The beach width was defined as the distance from de benchmark to the +2 contour; this criterion was chosen because most of the time, even during high tide, the subaerial sandy beach was visible above this contour. The volume of sand eroded or accreted between two successive profiles is then obtained by difference and it can be considered as the change of volume per unit length of beach in the longshore direction. The computed volumes were normalized by the profile length to allow proper comparison. The result is the volume of erosion/deposition per unit profile length ($m^3$/m/day).

Measured beach changes were compared to wave patterns, especially during the winter of 1998. Wave data were obtained from two sources: one set from a pressure sensor operated by Centro de Investigación Científica y Educación Superior de Ensenada (CICESE) off the breakwater of the CFE's power plant in Rosarito, with two recorded periods: from January 9 to February 13, and from March 18 to March 31, 1998; the second set was obtained from pressure sensors of the "Harvest Slope Array" located on an oil platform off Point Conception, U.S. and operated by the Coastal Data Information Program (CDIP). This data set was intended to fill the gap left by the Rosarito sensor and provide an idea of wave patterns during that period. Wave data from this source cover from February 10 to February 26; unfortunately no data are available for the period February 27 to March 18. It should be noted that proper correspondence between both data sets, processes like wave refraction, diffraction and angle of wave approach (in deep and shallow water) must be taken into account. However CCSWTS (1989) have estimated that sheltering of the islands off Southern California cause the waves to be 30% lower at the shoreline than in open ocean conditions. The CDIP data used for this study was reduced by this percentage and assumed to occur at Rosarito. To give a better idea of the wave heights reaching the coast, the breaker height was estimated for both data sets with the Komar and Gaughan (1972) criterion:

$$H_b = 0.39\ g^{1/5}\ (TH_0^2)^{2/5},$$

where $H_b$ is the breaker height; $g$ is force of gravity: $T$ is the wave period and $H_0$ is the deep water wave height.

## RESULTS AND DISCUSSIONS

The initial profiles of June 1997 illustrate the typical shape of a summer or swell profile with a relatively flat backshore, one or two berms, and a greater slope in the foreshore (see Figures 2, 3, 4, and 5). The maximum volume of sand contained in the beach occurs during July 1997, except in BN6 where it is observed in August 1997. The beach width decreases gradually from July-August such that by December 1998 the contour +2 has receded 27 m at BN11 and approximately 35 m at BN1 and BN6 (Figure 6). This pattern corresponds to a wave regime in which the average wave height has increased gradually from 1.5 m in August to 3 m in December (CDIP, 1998).

From January 14 to February 7, significant amount of energy was introduced to the beach system. Waves exceeding 4 m in height for nine or more consecutive hours are considered to be an extreme wave episode (Seymour, 1996; 1998) and four out of seven such events (*Hb* in our case) with a mean period ranging from 14 to 17 s have occurred (Figure 7) and particularly interesting is the event from January 30 to January 31, which lasted for 28 hours with significant duration of breaker heights of 5 m and periods up to 20 s (16 consecutive hours). From this fact only one could expect greater erosion of the beach and of the backshore because accumulation of water over the beach induces wave breaking closer onshore. In addition, this exceptional wave pattern coincided with a spring tide high tide (Figure 7), further increasing the destructive ability of the waves. This conditions caused the most severe erosion along the beach profiles during the period of study. The maximum volume of sand erosion occurred at BN11 (Hotel Rosarito Beach, 66.9 x $10^{-3}$ $m^3$/m/day) and at BN1 (San Antonio del Mar, 40.8 x $10^{-3}$ $m^3$/m/day). In the first case the berm was displaced 26 m shoreward (2.3 m/day, almost triple the estimated recession from November 15, 1997 to January 28, 1998), in addition to the 30 m (0.7 m/day) recession observed during the period from December 21, 1997 to January 28, 1998. In the second case, the significant sand erosion uncovered the rocky bottom, stopping de erosion of the profile but allowing a direct wave attack to the base of the seawall and adjacent cliffs.

Another significant effect of the erosion was the vertical displacement of nearly 4 m of the beach profile and as a result of the removal of sand, old wrecked residences as well as large debris from energy industry in the area were uncovered (Figure 8), making the beach useless for recreational purposes. The large waves combined with high tide caused flooding of several residences and destruction of others in the southern portion. Days prior to February 10, heavy rain caused the arroyo Rosarito, near benchmark BN11, to bring large amounts of wooden debris whose accumulation on the beach formed a 1 to 2 m high scarp (Figure 9) that helped to reduce further recession of the beach. It should be noted that most recreational activities that support the local economy take place on the beach stretch from Hotel Rosarito to a few hundreds meters south from the CFE's water intake, but this beach segment is precisely the

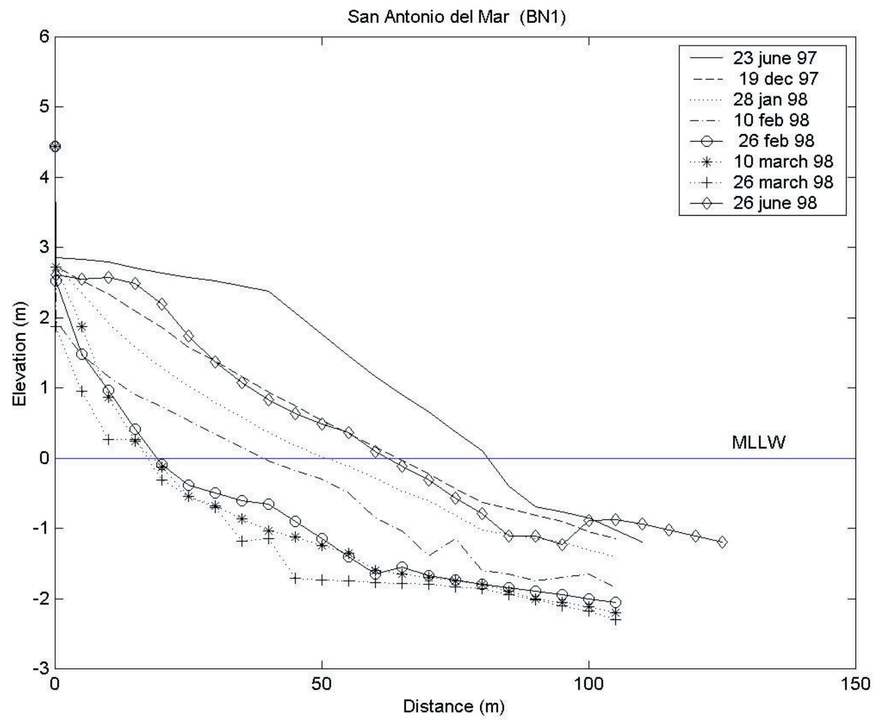


Fig. 2. Beach profiles at San Antonio del Mar (BN1). The profile sequence shows the typical beach change from summer to winter to summer, although the final profile is lower than the initial.

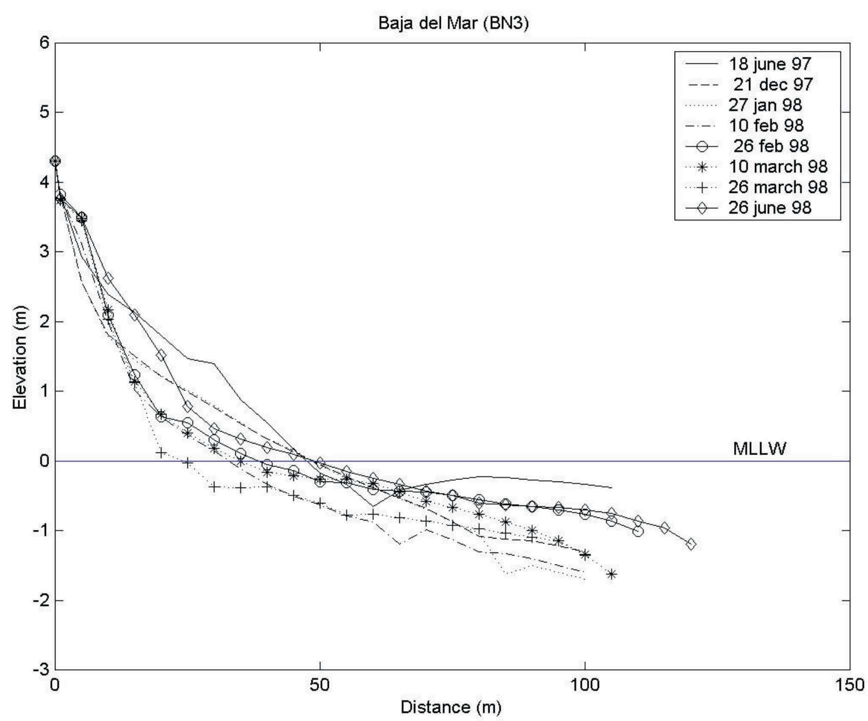


Fig. 3. Beach profiles at Baja del Mar (BN3). Seasonal changes are relatively small and most changes occurred in the lower beach; the upper beach gravel is re-covered with sand by June 1998.

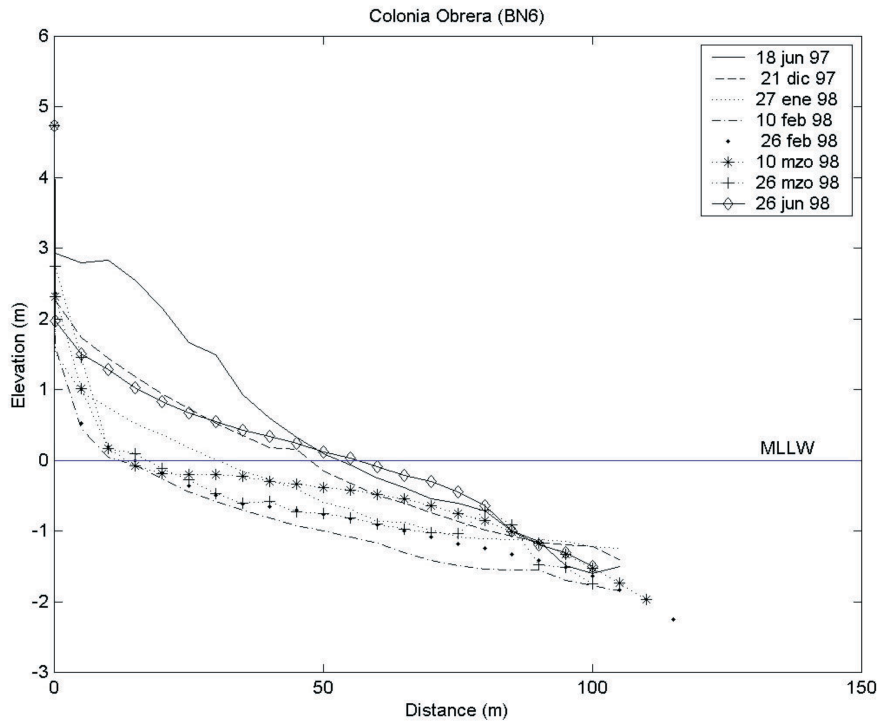


Fig. 4. Beach profiles at Colonia Obrera (BN6). The most significant flooding and destruction of residences occurred in the neighborhood of this section.

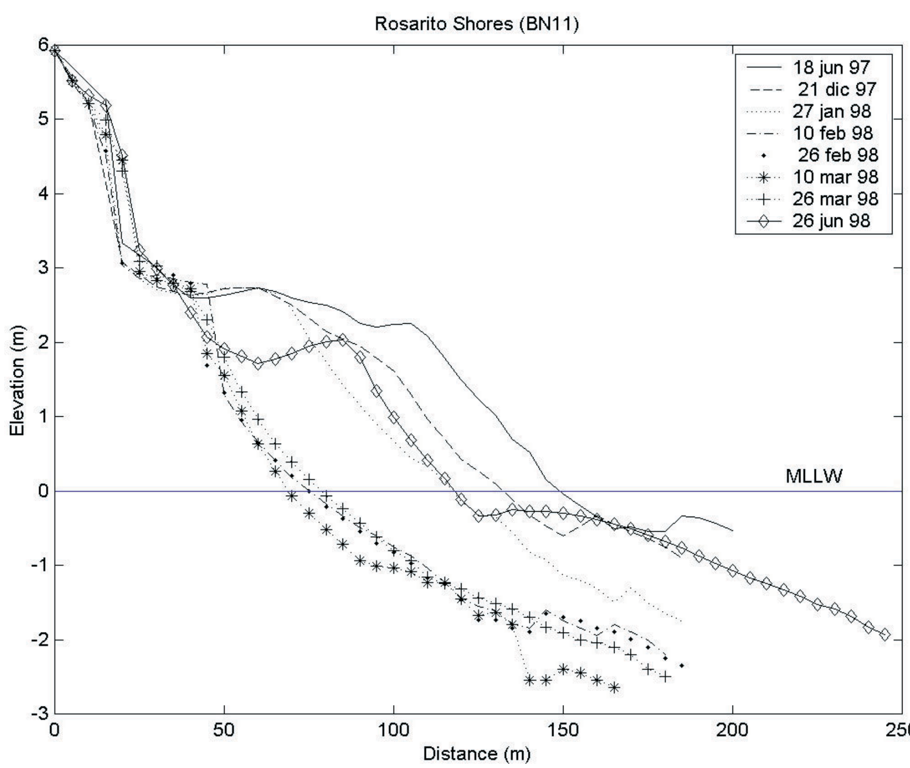


Fig. 5. The beach is widest in front of Hotel Rosarito (BN11). Since no coastal structure interfered with wave action, the berm stands despite substantial erosion.

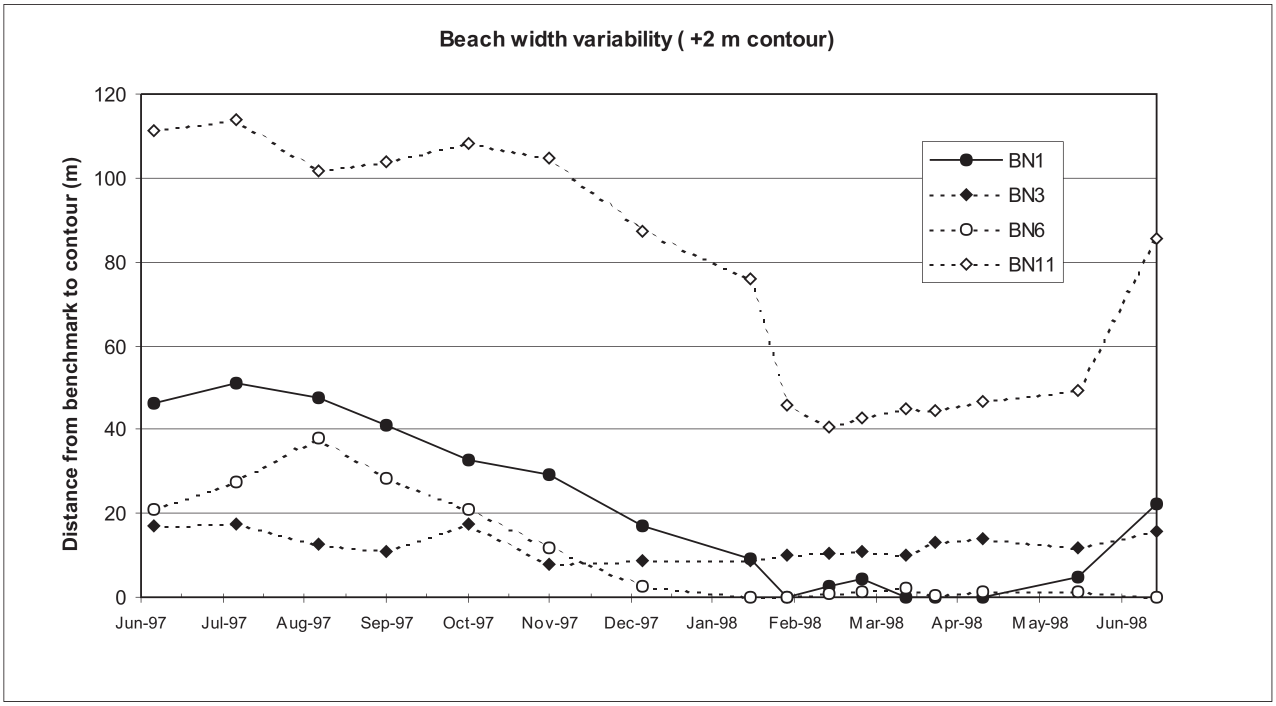


Fig. 6. Beach width variation. The positions of the +2 contour at BN1 and BN6 make these beach segments the most vulnerable to infrastructure damage, but at BN6 the beach plays an important role in protecting infrastructure.

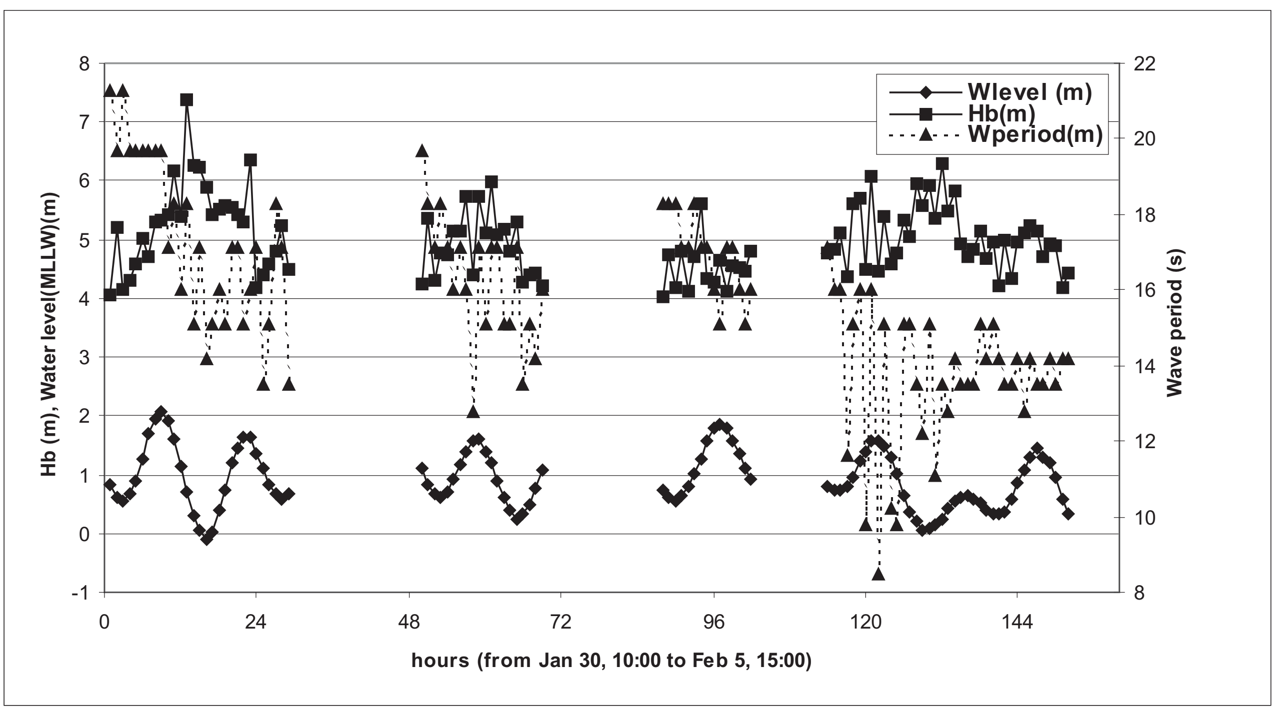


Fig. 7. Wave episodes exceeding 4 m high and lasting for more than nine consecutive hours arriving to Rosarito. The high waves (above 5 m) with periods up to 20 s during the first episode caused de rapid retreat of the beach along all profiles.

Fig. 8. Large debris from the energy industry and old wrecked residences in the area of Colonia Obrera (BN6) emerged after the arrival of the extreme wave episodes of January-February 1998.

Fig. 9. Accumulation of wooden debris brought up from the basin of the Arroyo Rosarito helped reduce beach recession off the Hotel Rosarito beach (BN11).

most sensitive to infrastructure damage under severe erosion conditions (Lizárraga *et al.,* 1998), hence the importance of preventing permanent losses of the beach.

Several events from February 10th to 26th as estimated from CDIP data, show breaker heights above 5 m (only the record with fewer gaps is presented in Figure 10), which occurred mostly during neap tides, so erosional/depositional effects were minor in all profiles (Figures 2, 3, 4 and 5). In the backshore of BN1 at the seawall toe, a gravel deposit 2 m high and 8 m wide was formed; similarly at BN3 the gravel deposit reached 3 m high and 17 m wide also at the seawall toe. It appears that those deposits increased mainly due to alongshore transport.

From February 26 to March 10, the BN1 is the only profile that shows depositional processes, which may result from the influence of the breakwater and groin of the water intake acting as sediment trap (Appendini *et al.,* 1997). From March 10 to March 26 all profiles show little variation. No wave data is available from February 26 to March 17, but data for the third week of March show that wave height as well as wave period were much lower than the January-February events (Figure 11), reducing the intensity of beach erosion. At BN1 no further erosion was possible because the rocky bottom started to emerge. The small deposition observed in BN11 might be due to redistribution of sand brought back from the area just beyond the breaker zone as onshore transport of sand is favored by the milder wave conditions.

From March 26 to June 1998, depositional processes predominated on all profiles, particularly at BN1 and BN11, where the average rate of sand accumulation is about 1.71 x 10-2 and 1.3 x 10-2 m3/m/day respectively; for BN3 and BN6 these values were smaller (0.58 x 10-2 and 0.51 x 10-2 m3/m/day).

It is interesting to note that the 1982-1983 El Niño's began during late spring, later than most previous event (Seymour, 1984). This delay caused the winter 1982 to be "normal", that is, not influenced by the ENSO event and thus with no significant erosion of the beach as shown by measurements made by Marmolejo-Lara (1985); but major destructive effects along the California and Oregon coast during the winter 1983 were reported (Griggs and Johnson, 1983; Komar *et al.,* 1989). From January to March 1982 at a site 100 m to the north of BN6 and under influence of relatively low wave heights (maximum wave height = 1.6m), we computed a net erosion rate of 2 x 10-3 m3/m/day. In

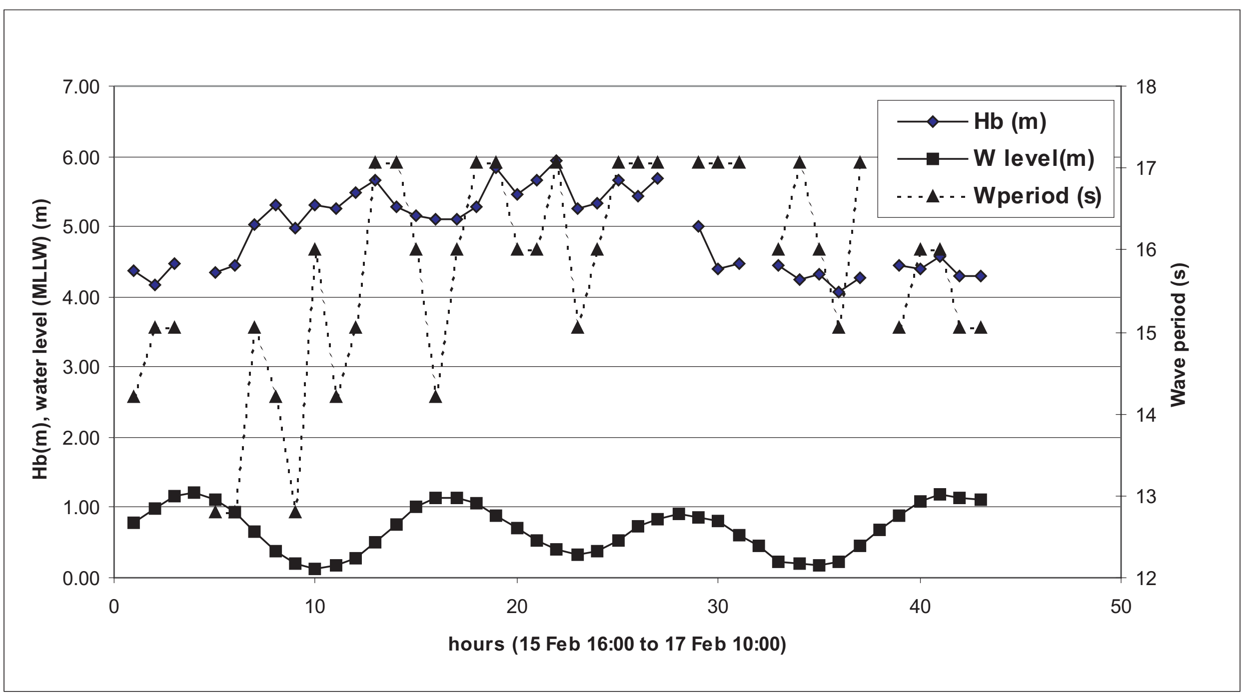


Fig. 10. Wave pattern as estimated from the Harvest Platform Array. Note that the whole event occurred during neap tides, reducing the effect on beach erosion.

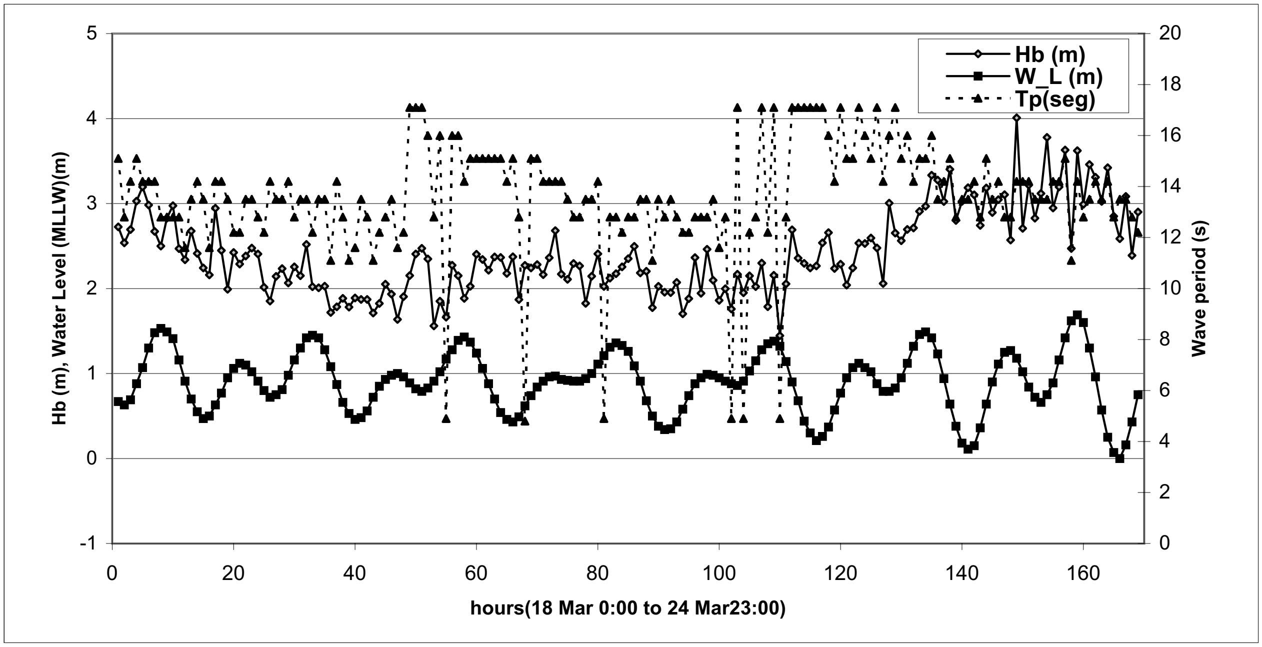


Fig. 11. Wave pattern off Rosarito shows wave height under 3 m high during the third week of March 1998.

contrast, for the same beach segment during the winter 1998 El Niño's the estimated erosion rate was 13.7 x 10-3 m3/m/day, greatly reducing the beach height and width (Figure 6) as a result of the storm severity and repetitiveness (Figures 7, 10, 11). Unfortunately no data is available to evaluate the effects on the beaches of Rosarito of the extraordinary storms observed during the winter of 1983 as a consequence of El Niño.

Vertical variation and maximum recession of the beach are important quantities for planning coastal protection and recreational uses. The maximum recession of the berm during the period of study was approximately 66 m at BN1 and in all other profiles the berm was totally and rapidly destroyed. The profile height varied from 1 to 2 m in BN3 and BN6 stations, while at BN1 and BN11 the variation reached 3.5 m. As can be seen in Figures 2 through 5, the greater variability of the berm position occurs at BN11; since this beach segment is the widest in the area (~150 m) and infrastructure is absent on the beach, the berm recede as much as the wave regime determines.

Initial and final profile comparisons (June 1997 to June 1998) shows the rapid reconstruction of the berm at BN1 and BN11 (Figures 2 and 5), but no reconstruction at BN6. For all profiles (except BN3) the final height is from 1 to 1.5 m below the initial profile. This indicates that erosion observed from January to March 1998 was so intense that for the final profile to reach the initial height, more than a single period of reconstruction (summer), might be necessary. The gradual growth of the beach has been reported form daily beach profiles by Katoh and Yaganishima (1988); they concluded that as erosional processes occurs, the shoreline recesses very rapidly (one or two days) depending on wave energy flux and previous position of the shoreline; by contrast, during accretionary processes, the shoreward shift of the shoreline is slow but constant.

## CONCLUSIONS

The beach at Rosarito showed a gradual process of erosion from summer 1997 to the beginning of winter 1998. The intense erosion observed during the first two weeks of February was caused by the arrival of a very energetic wave regime, greatly influenced probably by the relocation of the low pressure regions in the northwest and eastern Pacific due to the ENSO 1997-1998 event. The rate of change position of the berm (2.3 m/day) was three times larger than that observed during milder wave conditions. It is important to gain knowledge on the nature if the gravel deposits along the northern beaches of Rosarito since they play an important protective role of the costal infrastructure. It appears that beach reconstruction requires long period of low energy wave conditions like those observed in summer. Most coastal damage occurred to the south of the CFE's water intake and since these beaches are most important to the local economy, further observational program should be established to assess the variability of beach erosion and recovery.

**ACKNOWLEDGMENTS**

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