CHAPTER 231

HURRICANE OPAL INDUCED CHANGES ON NATURAL AND NOURISHED BEACHES, WEST-CENTRAL FLORIDA

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ABSTRACT

Twenty-six beach profiles were surveyed immediately after the passage of storm conditions and were compared with pre-storm situations. They include 1) eleven locations spread throughout the entire 60 km reach of the Pinellas County coast including wide, narrow, natural and nourished sites, with and without seawalls; and 2) 15 locations confined to three adjacent nourishment projects along 14 km of Sand Key.

The overall behavior of the nourished and natural beaches along the 60 km reach of coast was similar, displaying a general trend of 1) shoreline erosion ranging from 2 to 10 m, 2) upward and landward migration of the nearshore bar, and 3) backbeach accumulation and increase in the berm height. Shoreline orientation and beach sand composition played no significant role in beach performance during the storm. The technique of dry beach replenishment using a dragline and conveyer belt may contribute to the more severe shoreline erosion at the Indian Shores nourishment project as compared to the traditional pumping technique used at Indian Rocks Beach and Redington Beach.

Temporary berm accumulation and shoreline accretion were recorded at two chronically eroding locations downdrift of structures. The shoreline accretion was caused by the landward sand transport induced by the storm waves. The storm accumulation was eroded by the normal-weather longshore sediment transport within three months after the storm.

The current version of SBEACH model (Larson and Kraus 1989) failed to reproduce the Opal-induced beach changes in the surf zone. The unsuccessful prediction was attributed to the uncertainties in offshore wave measurement, and morphological and computational complications caused by the exposure of hard bottom in the nearshore region.

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INTRODUCTION

Hurricane Opal passed about 250 km to the west of the west-central Florida coast in its northerly path toward the Florida panhandle in early October, 1995. The speed of the hurricane center (Fig. 1) in the central Gulf of Mexico was relatively slow. The slow speed generated abnormally long-period, high waves in the Gulf. A storm surge of about 1 m was measured in the study area along the west-central Florida coast (Fig. 2). The energetic conditions and the storm surge lasted for approximately two days during spring tide conditions.

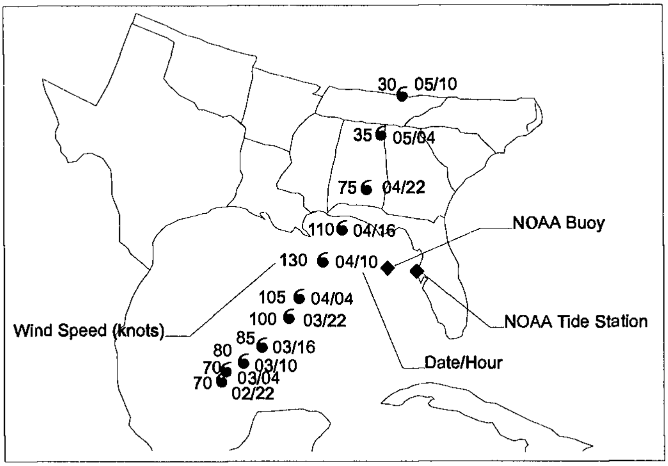

Figure 1. Storm track of Hurricane Opal and NOAA's wave buoy and tide gage.

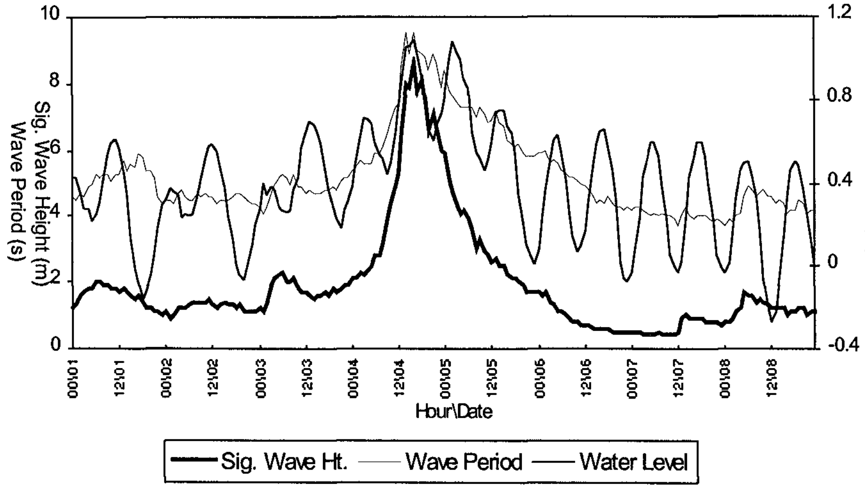

Figure 2. Measured significant wave height, average wave period, and storm surge by the NOAA buoy station 42036 and Clearwater tide station.

The significant wave height measured by the NOAA wave buoy (Fig. 1) reached a maximum over 9 m. Although the average wave period as shown in Figure 2 was less than 10 s, the dominant wave period reached 13 to 14 s during the peak of the storm. A storm surge of nearly 1 m was measured by the NOAA Clearwater tide station at the northern boundary of the study area (Fig. 2).

Twenty-six beach profiles were surveyed immediately after the passage of storm conditions and were compared with pre-storm profiles which were surveyed 1 to 2 months before the storm. Each profile was surveyed to a depth of 1.5 m below NGVD along a shore-normal transect. The 26 profiles are located along nearly 60 km of coast in Pinellas County, Florida and are part of an ongoing, long-term study of beach dynamics. Both natural and nourished beaches were included with construction ranging from 2 years old to nearly 10 years. The study area has a coastal orientation that ranges over about 40 degrees with a broad headland in the middle (Fig. 3). The shoreface gradient ranges from about 1:400 to 1:700 with the steepest being at the headland.

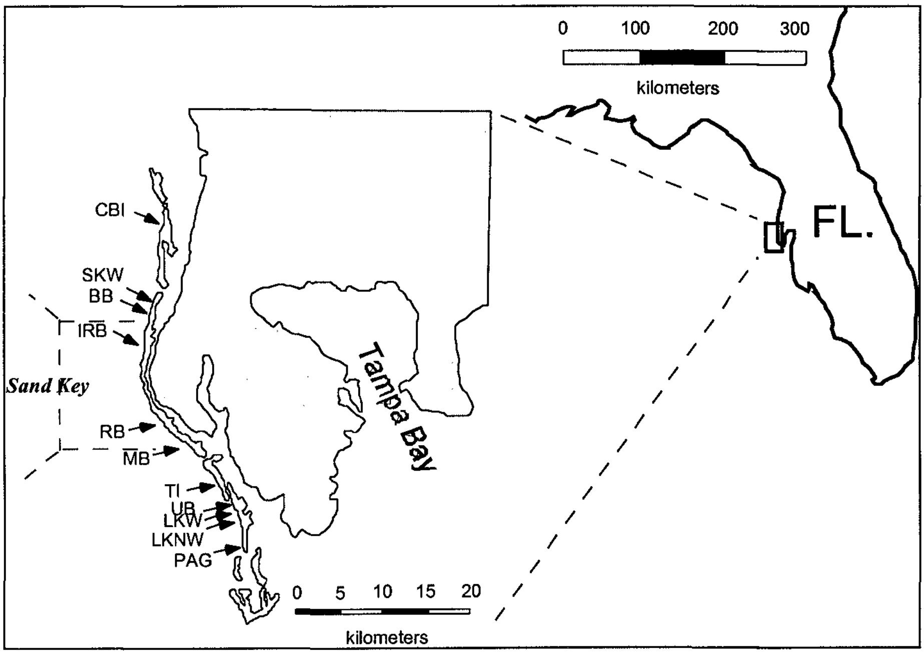

Figure 3. Study area in Pinellas County, Floirda. The eleven sites are indicated by the lettered arrows. The 15 nourished locations are equally spaced at 300 m intervals on central Sand Key.

The objective of this study was to examine the hurricane-induced beach morphology changes through the comparison of profiles surveyed before, immediately after, and 4 to 8 months after Hurricane Opal. Different types of beaches with different orientations and different degrees of human activities including natural and nourished, with and without seawalls, were examined and compared. Dominant direction of sediment transport during storm and normal-weather conditions is discussed. The application of the SBEACH model in predicting the storm induced beach changes along west-central Florida coast is also examined.

STUDY AREA

Two sets of profiles were surveyed: 1) eleven locations spread throughout the entire 60 km reach of coast including wide, narrow, natural and nourished beaches, with and without seawalls; and 2) 15 locations confined to three adjacent beach nourishment projects along 14 km of Sand Key (Fig. 3). The dominant longshore sediment transport along the entire coastal reach is toward the south, but there are local reversals. Two locations (SKW and UB), downdrift of structures, are experiencing severe beach erosion. SKW (Fig. 3) is currently protected by seawalls. The chronically eroding Upham Beach (UB in Fig. 3; Leonard et al. 1989, Dixon and Pilkey 1989) was protected by sand bags and renourished for the fifth time in the last 20 years in May, 1996.

Three adjacent beach nourishment projects were constructed on Sand Key. Five locations, R74, R75, R78, R80, and R81, were surveyed on Indian Rocks Beach which was nourished in 1990. The middle project at Indian Shores (R86, R87, R89, R91, and R92) which is located on the protruding headland was nourished in 1992 and the southern project at Redington Beach (R98, R99, R106, R107, and R108) was nourished in 1988. The nourishment at Indian Shores was constructed differently from the two adjacent projects. Instead of using the conventional pumping, the sand was replenished dry with a dragline and conveyer belt. The less expensive dry fill resulted in a looser packing than the wet pumping. The nearshore wave energy is usually higher at the Indian Shores headland due to the steeper shoreface gradient than at the adajcent Indian Rocks Beach and Redington Beach.

Sediment properties on natural beaches are different from those on the nourished beaches. Natural beaches or beaches that have not been nourished for the last decade or so are typically composed of well-sorted fine sand with less than 10% shell gravel. Nourished beaches, especially the two recently constructed at Indian Rocks Beach and Indian Shores, have significant amount of shell gravel, generally more than 20 %, inherited from the borrow material. Sediments in the swash zone have even higher shell-gravel concentration.

OPAL-INDUCED CHANGES ON NOURISHED BEACHES

All the nourished sites showed shoreline erosion of 2 to 10 m (Fig. 4A). The protruding 4-year old Indian Shores suffered the most shoreline loss, ranging from 8 m to over 10 m. The 8-year old Redington Beach lost the least shoreline, from 2 to 8 m. The 6-year old Indian Rocks Beach lost between 5 to nearly 10 m. The severe shoreline erosion at Indian Shores headland is believed to be caused by a combination of high wave energy and loose packing.

The sand-volume change above the -1.5 m NGVD datum was generally small, ranging from 15 m^3/m gain to 17 m^3/m loss (Fig. 4B). Although most of the locations lost 2 to 17 m^3/m sand, five of the 15 locations gained various amount of sand. The trend of volume change was not as apparent as the shoreline change. The reason for the less distinctive trend of volume change as compared to shoreline change was that the volume loss at the shoreline was compensated by the landward and upward migrations of the nearshore bar and the accumulation on the backbeach, forming a higher berm (Fig. 5).

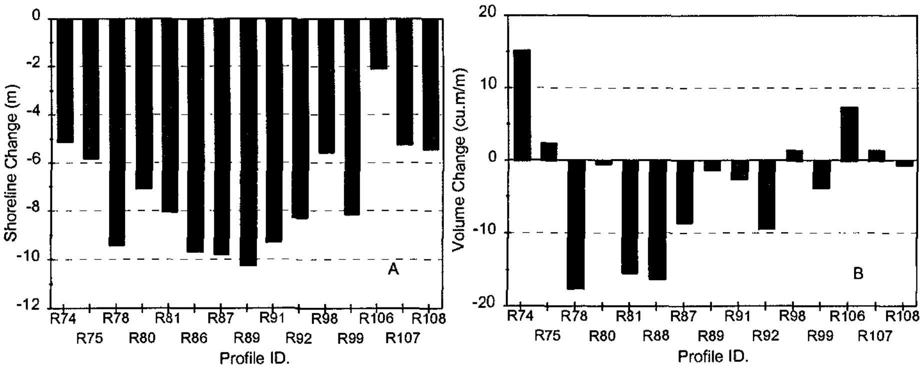

Figure 4. Shoreline (A) and volume (B) changes on the nourished beaches.

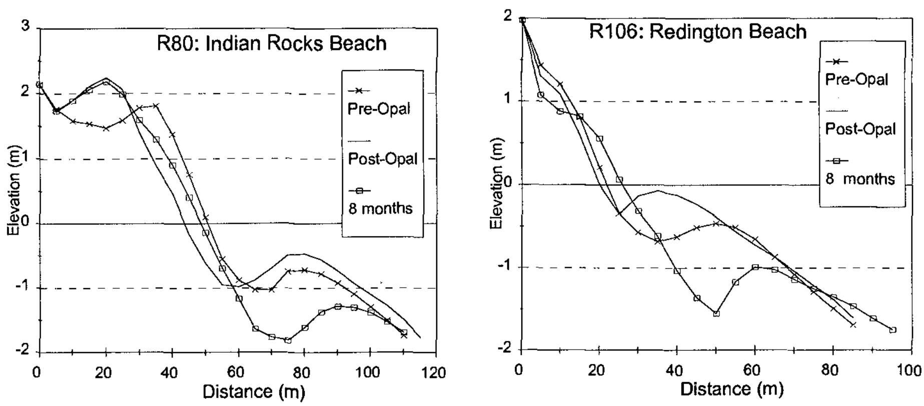

Figure 5. Beach profile changes: before, immediately after, and 8 months after.

It is generally assumed that large storm waves induce seaward migration of the breaker-point bar (e.g., Komar 1976, Dean 1995). This hypotheses which was developed from the original beach cycle study of Shepard (1950) has been used broadly in shoreface-development studies (e.g., Pilkey et al. 1991). Larson and Kraus (1994) documented landward sediment transport during 3 of the 4 examined storms in 1989 and 1991 at Duck, North Carolina. Lardward and upward migration of the nearshore bar induced by Hurricane Opal was measured on all the barred locations in the present study along the 60 km study area (Fig. 5). This landward migration of nearshore bar was also observed by Stone et al. (1996) on the Florida panhandle. Shoreline recovery and seaward migration of the nearshore bar was measured 4 and 8 months after Opal, indicating a seaward transport during the normal-weather conditions.

Seasonal beach cycles like those observed along the U.S. Pacific coast (e.g., Shepard 1950, Inman et al. 1993) are not observed along west-central Florida coasts. The landward migration of the nearshore bar observed in this study cannot be explained by the seaward shift of breaker point during high-energy storm wave conditions, which would result in seaward migration of the breaker-point bar. The unexpected upward and landward bar migration indicates that in addition to the wave steepness and the location of breaker point, the nearshore bar migration may be also controlled by other factors. Further study is needed to understand the mechanism of landward bar migration during storm conditions.

Another morphological change that was observed at all the profile locations except the "hot spot", R106 (Fig. 5B), was the accumulation on the backbeach. A large amount of sand was deposited landward of the previous berm crest. The berm crest was shifted landward and higher than before. The thickness of the wedge-shaped accumulation decreased landward and terminated, at most of the nourished locations, before the accumulation reached the seawalls. The backbeach accumulation was the thickest, up to 1 m thick at the storm-berm crest, on the high-energy Indian Shores headland, and the thinnest on the relatively low-energy Redington Beach.

Significant shoreline recovery and the seaward migration of the nearshorc bar were observed 8 months after the storm (Fig. 5). The shoreline recovery resulted in more gentler beach than the storm beach, especially in the vicinity of the shoreline. The backbeach accumulation remained unchanged because the storm berm crcst is beyond the reach of wave uprush under normal weather conditions.

Natural beaches or those that have not been nourished in the last decade or so (CBI, MB, TI, LKNW, and PAG in Fig. 3) showed a similar general trend, i.e., shoreline erosion, landward migration of nearshore bar, and backbeach accumulation, across the entire 60 km study area. The amount of shoreline retreat, ranging from 2 to 10 m, was similar to that measured on Indian Rocks Beach and Redington Beach and was less that that on Indian Shores (Fig. 6A) headland. Volume change above -1.5 m NGVD was generally small, mostly less than 15 m^3/m, and showed similar trend (Fig. 6B) as that observed on nourished beaches in Sand Key.

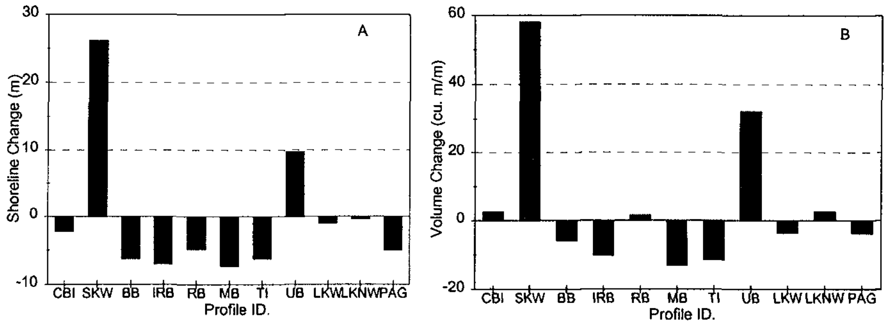

Figure 6. Shoreline (A) and volume (B) change of the 11 locations along Pinellas County, Florida.

OPAL INDUCED CHANGES ON THE CHRONICALLY ERODING STRUCTURED BEACHES

Two of the beaches that are historically erosional, SKW and UB (Fig. 3), are both downdrift of structures. Scour behind the seawall and damage to the adjacent residential buildings occurred due to storm wave over-topping at both locations. A significant amount of sand accumulation was measured in front of the seawall at SKW, and the sand bags at UB were buried by sand that was deposited on the beach (Figs. 6, 7). As much as 26 m of shoreline accretion with nearly 60 m^3/m volume gain was measured at SKW immediately after the storm. Ten meters of shoreline accretion and 35 m^3/m volume gain were measured at UB just south of the wave-dominated inlet, Blind Pass (Davis and Gibeaut 1990). Large carbonate rock fragments characteristic of the Tampa Limestone which is exposed offshore were found on the storm beach, indicating that the sediment was transported landward from offshore during the storm. It is believed that the seawalls and sand bags induced significant energy dissipation during the storm surge. The fast rate of energy dissipation resulted in backbeach accumulation above the normal wave uprush limit.

The temporary sediment accumulation induced by Opal was eroded completely within four months after the storm (Fig. 7). The longshore transport under normal weather and the lack of updrift sediment supply are believed to be responsible for the erosion. The southward transport is evident at Upham Beach (UB) from the most recent beach nourishment. A profile, LKW (Fig. 3), about 150 m south of the UB location, was surveyed as part of a long-term beach monitoring program. A large amount of sediment was replenished on the Upham Beach about 7 months after the storm. The LKW location was about 80 m south of the nourishment project. Significant shoreline erosion was measured at UB only 3 months after the nourishment (Fig. 8). Remarkable accumulation was measured at the LKW location during the same period. The shape and slope of the shoreface at Upham Beach remained fairly constant, suggesting that the shoreline retreat was not caused by the cross-shore profile adjustment. It is evident that the southward longshore transport is the cause of the long-term beach erosion at Upham Beach as well as the erosion of the storm accumulation from Opal.

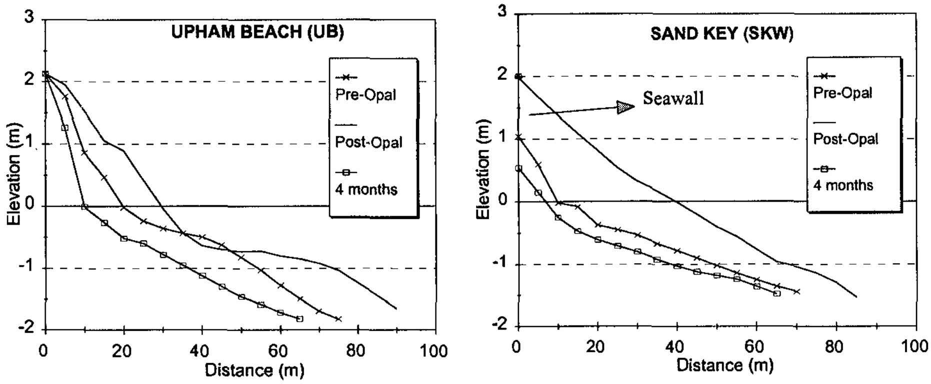

Figure 7. Temporary accumulation induced by Hurricane Opal on structured beaches.

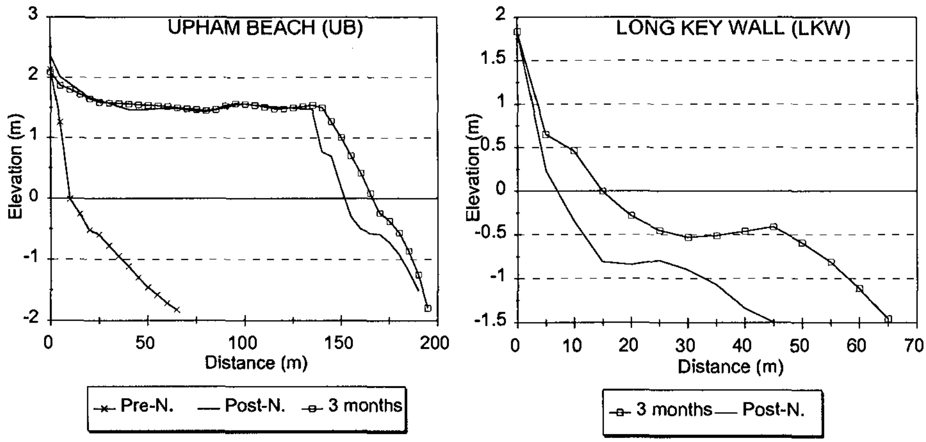

Figure 8. Shoreline erosion at the recently nourished Upham Beach and sand accumulation at the downdrift beach. Note the differences in scale.

The seawall and stablizing sand bags effectively protected the coast and dissipated a significant amount of wave energy during Hurricane Opal. The structures are not capable of controlling regional and long-term beach changes caused by longshore sediment transport. Beach nourishment not only provides a buffer for normal weather shoreline erosion caused mainly by longshore sediment transport but also protects the coasts against dramatic storm events.

SBEACH MODELLING OF THE BEACH PROFILE CHANGES

SBEACH, the numerical model for simulating storm-induced beach change (Larson and Kraus 1989), was applied to reproduce the Opal-induced beach profile changes along west-central Florida coast. The offshore wave condition measured at the NOAA's 42036 wave buoy and the water level measured at the NOAA's Clearwater tide station (Fig. 2) were used as the key hydrodynamic input data. The numerical modeling was applied to the 15 locations on Sand Key. An average grain size of 0.33 mm obtained from over 1100 samples was used to represent the sediment. The model was calibrated at two locations, one at the northern Indian Rocks Beach and one at the southern Redington Beach.

Examples of SBEACH modeling are illustrated in Figure 9. The trend of shoreline erosion induced by Hurricane Opal was successfully reproduced by the SBEACH model, although the magnitude of the shoreline erosion was over predicted. The backbeach accumulation and the unexpected upward and landward migration of the nearshore bar were not predicted. The bar/trough features were basically absent from the predicted profiles. The increased berm height and the wedge-shaped sediment accumulation on the backbeach were not predicted, on the contrary, significant berm erosion and a much gentler beach slope near the shoreline, as compared to the pre-storm situations, were predicted.

The unsatisfactory SBEACH modeling is believed to be caused by the uncertainties in input wave data and regional morphological and geological complications. A significant wave height of over 9 m with a relatively short wave period of less that 10 s was measured by the NOAA's 42036 wave buoy offshore west-central Florida. The 9 m significant wave height was much larger than that observed in the nearshore (3 to 4 m, as printed on the local newspaper). The over-predicted backbeach erosion is believed to be caused by the possibly exaggerated wave height. This assumption was proved by using an arbitrary smaller wave height of 3.5 m. Much less backbeach erosion was predicted with the smaller input wave height.

The nearly horizontal hard bottom composed of Tampa Limestone violated the bottom boundary condition of movable sand assumed in the current version of SBEACH. The depth of the hard bottom decreases from north to south. At northern Indian Rocks Beach, the hard bottom is exposed at 7 m, the depth decreases to about 3 m at the southern Redington Beach. Based on the wave breaking criterion used in the SBEACH model (Larson and Kraus 1989), the nearly horizontal hard bottom is within the breaker zone during the peak of the storm conditions with over 9-m waves. The current version of SBEACH is not capable of incorporating the non-erosible hard bottom, especially when the hard bottom is within the breaker zone. The above situation will be an ideal field test for the updated SBEACH model (N.C. Kraus, personal communication; available:

December 1996, Randy Wise, personal communication) which will incorporate the influences of non-erosible bottom.

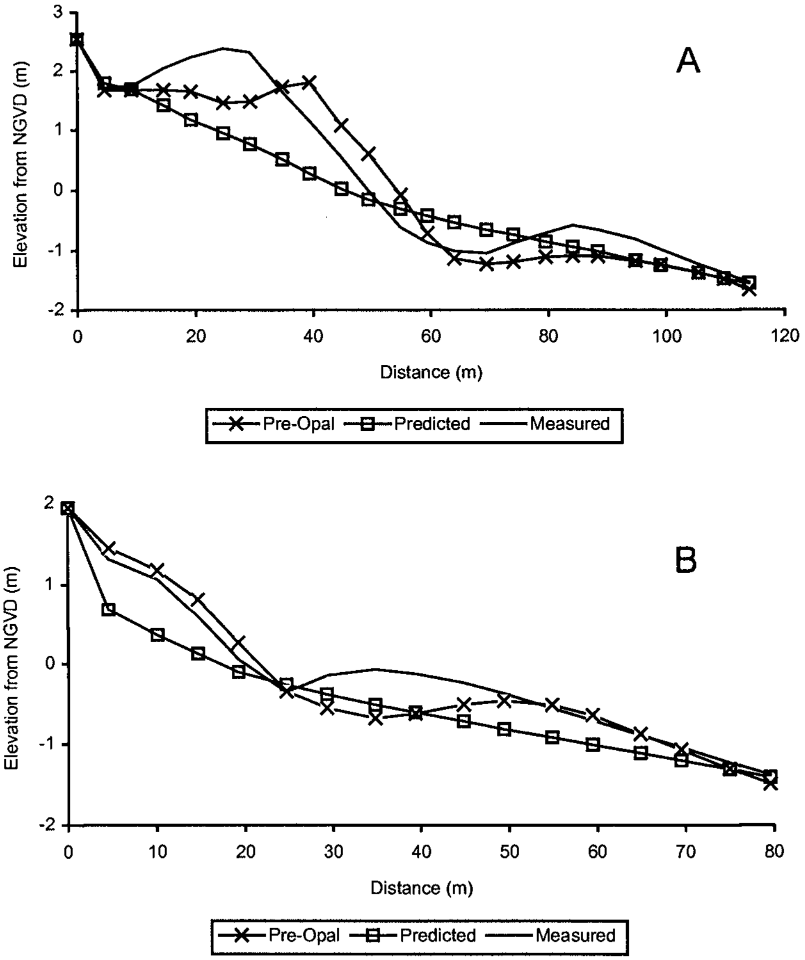

Figure 9. Measured and predicted beach profiles; A) R74, Indian Rocks Beach; and B) R106, Redingtion Beach.

SUMMARY AND CONCLUSIONS

The overall behavior of the nourished and natural beaches during the passage of Hurricane Opal is similar. All surveyed beaches along the 60 km reach of coast displayed a general trend of shoreline erosion, upward and landward migration of the nearshore bar, and accumulation on the backbeach resulting a higher berm. This trend was observed on beaches with different orientations and different sediment compositions, ranging from less than 10% shell gravel on natural beaches to greater than 30% shell gravel on nourished beaches. This indicates that shoreline orientation and sand composition played no significant role in beach performance under storm conditions.

It is apparent from the data collected on the three adjacent and differently constructed nourishment projects on Sand Key that they behaved differently. The oldest showed least change and the most recent showed the most. The most recent project was also constructed without the benefit of dredging and pumping, thus creating a loosely compacted beach. The loose packing contributed to the greater rate of erosion.

The two chronically eroding locations downdrift of structures behaved differently from the nourished and natural beaches. Significant shoreline accretion was measured at the two locations, with one protected by seawalls and the other protected by sand bags, immediately after the storm. A large amount of sand accumulated on the beach in front of the structure resulting from the storm-induced landward transport. The temporary storm accumulation was eroded by the normal-weather longshore sediment transport within 3 months after the storm.

The current version of SBEACH model failed to reproduce the Opal-indueed beach changes along west-central Florida coast. The unsuccessful prediction is attributed to uncertainties in input wave data and the model's limitation in incorporating the non-erosible hard bottom in the study area into the computation.

ACKNOWLEDGEMENTS

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