Impacts of Hurricanes Frances and Jeanne on Two Nourished Beaches along the Southeast Florida Coast

By

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ABSTRACT

Site inspections and beach profile surveys of nourished beaches in the city of Boca Raton, and Town of Palm Beach, Florida show that the nourished beaches protected the shore from hurricane impacts in 2004. Striking the southeast coast of Florida within 20 days of each other, Hurricane Frances (Sept. 5, 2004) and Hurricane Jeanne (Sept. 25, 2004) had hurricane-force winds extending more than 120 miles from the center. The eye of Frances made landfall as a Category 2 storm and Jeanne made landfall as a Category 3 storm on the Saffir-Simpson Hurricane Intensity Scale. Above-average waves and surge affected the entire Florida east coast.

Although these beaches were on the return or weak side (southwest quadrant with winds from the southwest as the eye traversed the shore) of both hurricanes, hurricane-induced waves affected the coast at least three days prior to landfall. Field inspection of the study sites after the passage of both hurricanes showed significant beach erosion and loss of berm elevation. Damage to infrastructure landward of the nourished beaches was minimal while non-nourished beaches located a few miles to the north and south of the renourished beaches sustained some damage.

Beach profile surveys indicated that, as a general trend, beach and inner surfzone erosion was accompanied by the formation of well-developed storm bars seaward of pre-storm bars. Beach morphological responses at the town of Palm Beach were a function of offshore geomorphology of the reef system and the presence of high relief rock outcrops located within the surf zone. Sand that eroded from the renourished beach was deposited seaward of rock outcrops in the surf zone but the rock outcrops had no measurable sediment build up. Causes of the magnitude and trends of beach performance are hypothesized in an effort to explain the observed beach behavior.

INTRODUCTION

Post-storm beach profile surveys were conducted on two nourished beaches to evaluate the impacts of Hurricane Frances and Hurricane Jeanne. The purpose of this paper is to compare these post-storm data with antecedent data sets to assess the performance of these nourished beaches under the high-energy conditions induced by the 2004 hurricanes. The pre- and post-storm beach surveys provided elevation data that was used to (1) depict cross- and alongshore morphological changes and to (2) quantify hurricane-induced volumetric changes of the projects investigated.

The nourished beaches investigated in this paper, Boca Raton and the town of Palm Beach (Figure 1), were directly impacted by Hurricanes Frances and Jeanne which struck the southeast Florida coast within 20 days of each other on Sept. 5 and Sept. 25, 2004, respectively. The approximate hurricane tracks and affected coastal segments are shown in Figure 1. Both storms had hurricane-force winds (*i.e.*, velocities in excess of 74 miles per hour) extending more than 120 miles from the center. The eye of Frances made landfall as a Category 2 storm and Jeanne made landfall as a Category 3 storm on the Saffir-Simpson Hurricane Intensity Scale.

Above-normal waves and surge affected almost the entire Florida east coast. Although the study beaches were on the return or weak side of both hurricanes (southwest quadrant with winds backing from the southwest as the eye traversed the shore), above-average waves attacked the studied beaches for a significant period of time. Deepwater significant wave heights of 29 feet and 28 feet during Jeanne and Frances were respectively recorded by a wave buoy offshore Cape Canaveral, located north of the study beaches. Field inspection of the three study sites after the passage of both

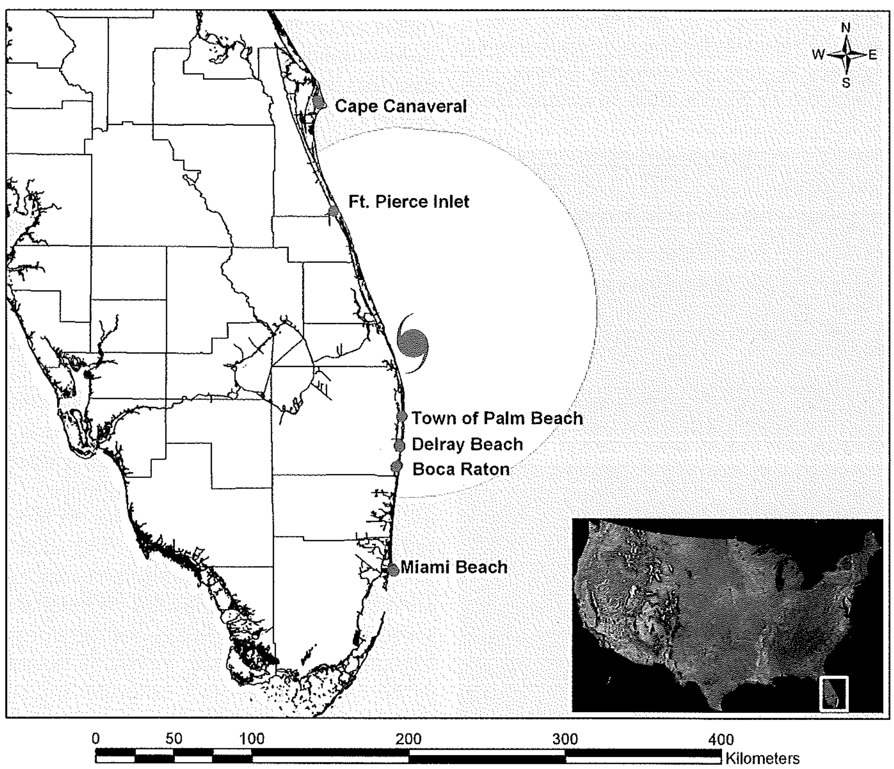

Figure 1. Location of nourished beaches along the southeast coast of Florida. The towns of Palm Beach and Boca Raton are of the study areas reported in this paper. The light-colored circle indicates the approximate area affected by hurricane-force winds during landfall. Hurricane Frances made landfall on Sept. 5, 2004, while Hurricane Jeanne made landfall at the same general location on Sept. 25, 2004.

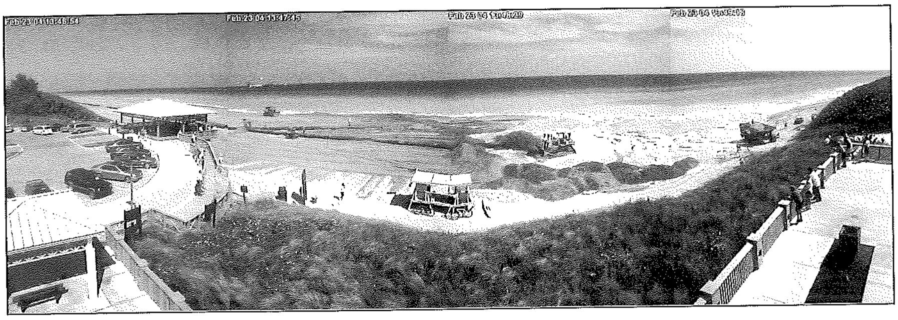

Figure 2. Central Boca Raton under construction, Feb. 23, 2004.

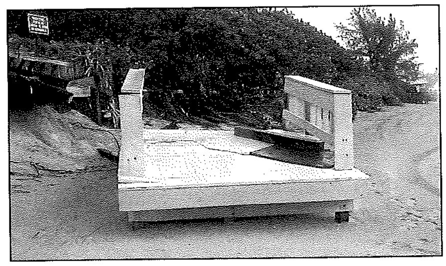

Figure 4. Damage to the park infrastructure just north of the central Boca Raton nourishment project.

hurricanes revealed significant beach erosion and loss of berm elevation. Subsequent beach profile surveys showed the formation of well-developed storm bars seaward of pre-storm bars. Beach nourishment performance is summarized in this paper and hypothesis to explain the observed beach behavior are presented.

CENTRAL BOCA RATON NOURISHMENT PROJECT

About 1.5 miles of central Boca Raton (between profile monuments R216 and R222) were nourished in February-March 2004. Although comparisons between surveys conducted in February 2004 and April 2004 showed an overall accretion of 656,000 cy of sand between monuments R216 and R222, the dredge contractor reported a placement of about 480,000 cy during construction. The nourishment was finalized six months prior to hurricane landfall. A post construction survey was conducted in March 2004 in central Boca Raton and a post storm survey was conducted on Sept. 10-18, 2004, after the passage of Hurricane Frances and soon before the arrival of Hurricane Jeanne. A photograph of the project under construction is shown in Figure 2. Photographs obtained during and after the storm passage show that the upland infrastructure and dune habitats were efficiently protected by the nourishment project (Figure 3). Buildings near the south end of the project, dunes and the Boca Raton pavilion (from where the photos of Figure 3 were taken) suffered no significant damage from the 2004 hurricanes. In comparison, intense dune escarpment and destruction of park infrastructure such as dune walkovers, recreational areas and lifeguard towers was observed in a non-nourished area located 2,000 ft updrift from the Boca Raton project area at Red Reef Park (Figure 4).

Figure 3. The Boca Raton project area soon after the passage of Hurricane Frances and Hurricane Jeanne. The top photograph is a south directed view while the bottom photograph is the view to the north.

As a consequence of Hurricane Frances, the Boca Raton project experienced about 80 feet of average shoreline retreat. Shoreline retreat was greater near Florida Department of Environmental Protection (FDEP) monument R-217 in the northern boundary of the project where it reached 135 feet (Figure 5). However, due to the short interval between construction and storm landfall, it is inferred that a portion of the retreat was due to construction template equilibration. The beaches to the north and south of the project area were eroded with exception for the segment immediately south of the Boca Raton inlet. The area south of the inlet experienced an average accretion of 46 feet due to sand impoundment against the jetty. The accretion south of the Boca Raton inlet may be attributed to strong northward currents observed soon after the passage of the storm. The hot spot observed at R-217 seems to be related to project template adjustment and end losses from the nourishment template as this was the area that received more unit volume of sand per linear foot of shoreline (CPE, 2004; Benedet, et al., 2005).

Volumetric changes along the project area per depth contours are shown in Figure 6. It is noted that most of the erosion occurred from the toe of the dune to the -12 foot to -13 foot depth contours and deposition occurred mostly from the -12 feet to -22 feet contour. Most of the erosion was verified on the subaerial beach as the recently built fill construction template adjusted cross-shore (240,000 cy, 30 cy/foot eroded from the toe of dune to the 0 foot contour). The total erosion from the toe of dune to the -12 foot contour was -421, 500 cy (53 cy/foot), the deposition from the -12 foot contour to the -30 foot depth was 285,500 cy (36 cy/foot). Therefore, the net volume loss along the project area (R-216 to R-222), between the dune to the -30 foot depth contour, was -136,000 cy (17 cy/foot), which is roughly equivalent to 28 percent of the original volume placed by the dredge contractor. On the other hand, the volume loss to the design closure depth (-18 feet) was -222,000 cy (28 cy/foot), which is roughly equivalent to 46 percent of the volume placed by the contractor. Because good closure was observed in the profiles it is inferred that the net volume change to the – 30 foot contour was lost by alongshore sediment transport while the changes to the design closure of -18 feet correspond to the volume lost form the project template by alongshore and cross-shore processes.

Typical cross-shore profile response is illustrated in Figure 7. The cross-sectional profiles shown in Figure 7 show the beach and inner surf zone erosional cut and the formation of a large offshore bar roughly between the -10 and – 22 foot elevation contours. This beach cut and offshore bar formation is typically observed after major storms (e.g., Moore, 1982, Morton, 1988, Larson and Kraus, 1989) and is also demonstrated in several other papers in this issue (e.g., Browder and Douglas; Keehn and Armbruster; Pierro and Neal, this issue). The cross-sectional profiles shown in Figure 7 also illustrate that, despite the large erosion of the subaerial beach experienced during Frances, the post-storm beach profile still has a much wider beach than the pre-construction profile.

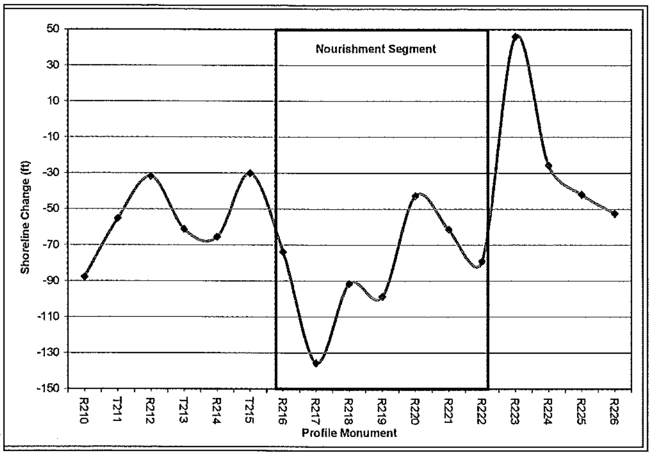

Figure 5. Shoreline changes between the post-construction survey conducted in March 2004 and the post-hurricane survey conducted Sept. 10-18, 2004. Survey area was mainly erosional except in the area immediately south of Boca Raton inlet (FDEP monument R-223) due to sand impoundment against the jetties. The project area eroded an average of 80 feet, maximum erosion of 135 feet occurred at R-217, near the northern end of the project. Alongshore distance is represented by the profile monuments, which are spaced approximately 1,000 feet apart.

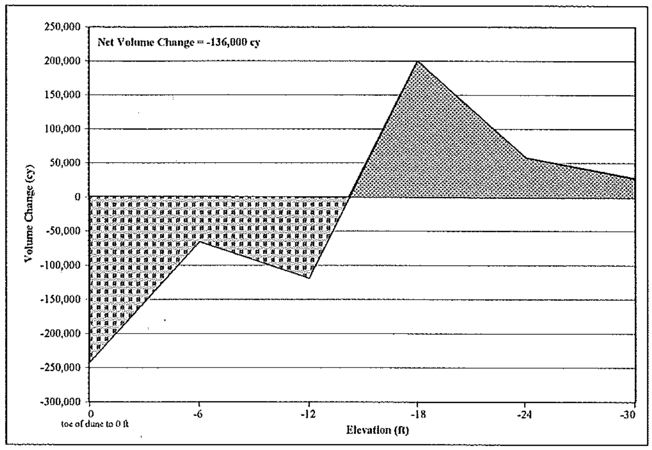

Figure 6. Volumetric changes along the Boca Raton project area. Sediment eroded from the toe of the dune to the 0 foot elevation and deposited from around the -12 foot elevation to -22 feet. Volume changes are minimal seaward of the – 22 ft contour are minimal. The peak of erosion was observed at subaerial beach while the peak of deposition was observed around -18 feet deep.

TOWN OF PALM BEACH – MID TOWN BEACH NOURISHMENT PROJECT

Town of Palm Beach was nourished in January-February 2003 with about 1.2 million cubic yards along 2.5 miles of beach, this nourishment segment extended from the FDEP monuments R-90 to R-101. Project construction was finalized on February 2003, about 1.6 years prior to the landfall of the 2004 hurricanes. Post-construction surveys were conducted on March 2003, and one-year post-construction monitoring surveys were conducted on April 2004. Post-hurricane surveys along the project area were conducted in October-November 2004, after the passage of Hurricanes Frances and Jeanne.

A photograph of the project under construction is provided in Figure 8. The property on the right side of the photograph is the internationally famous The Breakers hotel. Originally constructed in 1896, the property was one of the first major developments of the barrier island. After the passage of Hurricanes Frances and Jeanne, little beach was left in front of The Breakers, nevertheless the large beachfront property sustained minor wave damage from the storms because a nourished beach was in place prior to the storms. The public beach about a mile south of The Breakers experienced no significant damage from the two hurricanes, as shown in Figure 9. For comparative purposes, a picture of non-restored beach just south of the nourishment project is provided in Figure 10. This non-nourished area suffered significant dune escarpment and the buildings were undermined.

A qualitative indication of the magnitude of the storm is shown in Figure 10, where the Lake Worth fishing pier (indicated by the arrow on Figure 10) was almost totally destroyed. The coast north of the project area (25 miles to 200 miles north) was directly hit by Hurricane Frances and Jeanne; in these segments, the damage to coastal infrastructure, especially along non-nourished beaches, was significantly larger than at the town of Palm Beach as shown by other papers in this special issue (see Clark, and Barker and Bodge, this issue).

Shoreline and volume changes were calculated for this project between April 2004 (the last survey before the 2004 hurricanes) and October 2004 (the post-hurricane survey). The offshore geomorphology along the project area is of interest to better understand post-storm project response. Nearshore rock outcrops with 1-4 foot relief occur thoughout the area at depths around -12 to -18 feet (within the surf zone during high energy conditions). Offshore reefs occur in -40 to -100 feet of water. The offshore reef system transitions from a low-relief step-like sequence of multiple reefs located in deeper water (-80 to -100 feet) north of FDEP monument R-92 to a single shore-parallel reef located in shallower water (40-foot crest) located south of R-94. A gap on the offshore reef system occurs from R-92 to R-94 (Figure 11). An erosion hot spot was located landward of R-93, where the deeper and steeper shelf transitions to a shallower shore-parallel reef with a feature similar to a reef gap.

As a consequence of Hurricanes Frances and Jeanne, the town of Palm Beach project eroded an average of 39 feet. Maximum retreat of 120 feet was verified at R-93, an area which is located landward of the offshore gap on the reef system. Large alongshore variability on the shoreline change patterns was observed along this project, as indicated by Figure 12. While an erosional hot spot with total shoreline retreated of about 120 feet was observed

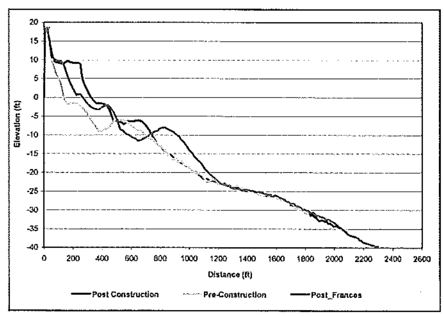

Figure 7. Typical cross-shore response of the Boca Raton nourishment project.

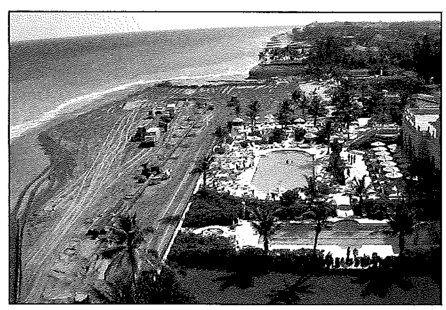

Figure 8. Construction of the Palm Beach 2003 beach nourishment project. The area illustrated is located south of The Breakers (between R-94 and R-95).

Figure 9. The Palm Beach Mid-Town nourishment project area soon after the passage of Hurricane Frances and Jeanne. The photograph was taken from FDEP monument R-98, view looking towards the north. The photograph was taken during the post-hurricane beach profile surveys (notice the survey level instrument on the lower left corner of the

around R-93, the area around R-90 located only about 3,000 feet to the north accreted. The nourished segment was mostly erosional while the beach at the profile monuments immediately to the south and north of the project area accreted, this accretion may be explained by alongshore dispersion of the nourishment sand.

Volumetric changes along the project area per elevation contour are shown in Figure 13. The town of Palm Beach experienced mostly erosion from the toe of the dune to the -12 to -13 foot contours and deposition from -12 to about -30 feet. About 67 percent of the total erosion was measured on the subaerial beach (228,600 cy or 18 cy/foot). The total erosion from the toe of dune to the -12 foot contour was -339,700 cy of sand (27 cy/foot); the deposition from the -12 foot contour to the -30 foot depth was 329,000 cy (26 cy/foot). The net volumetric change along the project area, from the toe of dune (or base of seawall where present) to the -30 foot depth represent only about 1 percent of the original placed volumes (-10,700 cy along 2.4 miles, 1 cy/foot). Because the profiles exhibited good closure, the minimal net changes indicate very low losses of sediment by alongshore transport processes. On the other hand, net volumetric changes to the -18 foot contour were about -285,500 cy (23 cy/foot), which corresponds to about 24 percent of the original placed volume (alongshore and cross-shore). Therefore, most of the losses from the project template were due to cross-shore transport in this area.

Representative cross-sectional profiles for pre-post storm conditions are illustrated in Figure 14. The profile located at monument R-93 was obtained in the center of the area of the erosion hot spot. Relative to profile R-97, large erosion of the subaerial beach to the 5 foot contour, and mild erosion from -5 to -15 feet was observed in this profile. A similar behavior continues to about 1,000 feet to the north and 500 feet to the south of this profile (Benedet, et al., 2005). Although this is the area of highest erosion along the project, no offshore deposition was observed and profile mobility along the hot spot region seemed to be limited seaward by rock exposures around the -10 to -14 foot contour. Because no offshore deposition was observed within the hot spot reach (and no overwash occurred), it is inferred that the sand eroded from the beach segment identified as a hot spot was transported alongshore.

The profile at monument R-97 shows subaerial beach erosion of less magnitute than R-93, however large offshore deposition is observed between the -14 to -27 foot depth contours in this profile (Figure 14). Similar behavior was also observed for distances up to 3,000 feet to the north and 4,000 feet to the south of this profile in neighboring profiles. It is interesting to note that no sand deposition was measured on the rock outcrops located between -9 to -14 feet, within the surf zone; instead, sand migrated over the rock and deposited seaward of it, forming a widespread offshore bar between -14 to -27 feet deep. This pattern seemed to predominate throughout the project area (except for the hot spot location near monument R93), for most

Figure 10. Non-nourished beach located less than five miles south of the Palm project. Notice the undermined structures on the right-hand side of the photograph and the destroyed fishing pier indicated by the black arrow.

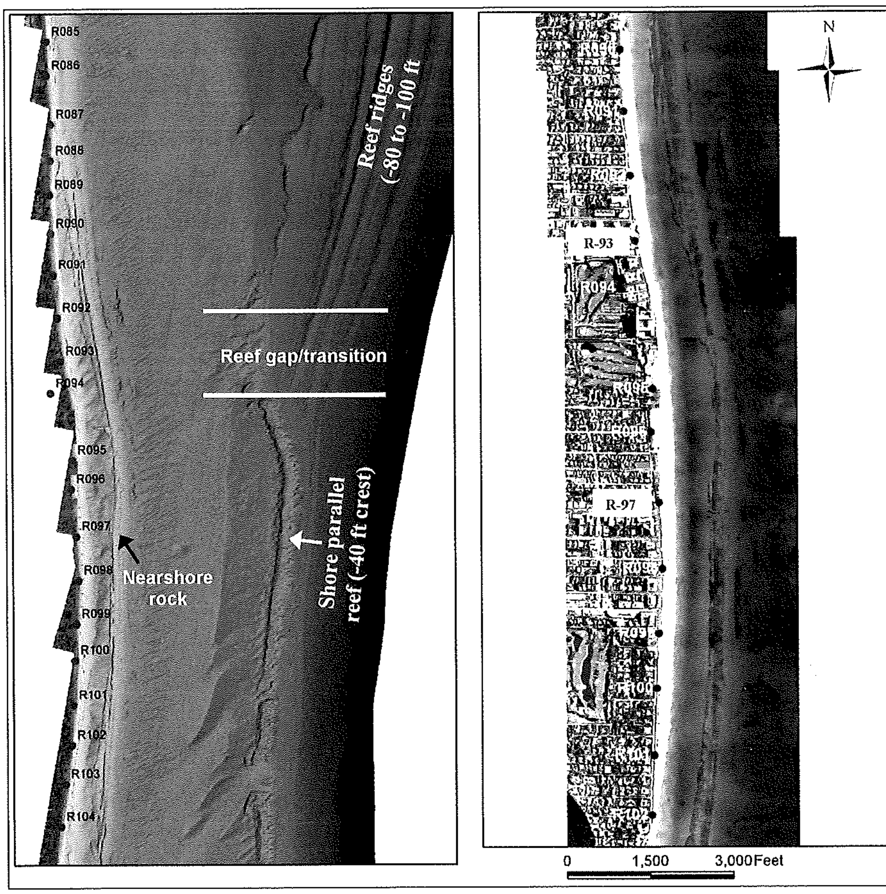

Figure 11. Three-dimensional representation of seabed geomorphology using detailed laser airborne bathymetric survey (image to the left) showing major features described in this paper viz. reef gap, shallow-water shore-parallel reefs and deeper-water reef ridges. The ridge line that extends from R-89 to R-104 is the high-relief rock outcrop. These rock outcrops are also evident on the contrast enhanced vertical aerial photograph mosaic of the project area (image top the right). Changes pre- and post-storm on R-93 and R-97 are shown in Figure 13.

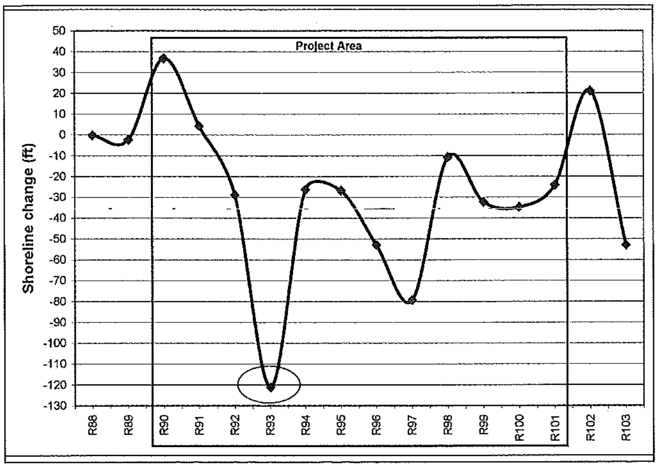

Figure 12. Shoreline changes of the Palm Beach project area (area inside the box) and neighboring beach segments. An area of increased erosion classified as a hot spot is observed at R-93 (circled point).

part the rock outcrop crest and adjacent area remained clear of sediments. Because the rock outcrops have very steep seaward slopes (see Figure 14) it is unsure whether asymmetry driven onshore transport may lead to natural sand recovery for this project.

PERFORMANCE COMPARISON

An average shoreline retreat of 80 feet was observed at the nourished beach of Boca Raton while the town of Palm Beach eroded an average of 39 feet. About 46 percent of the original project placed volume was lost from the project template (beyond the design closure depth and alongshore) at Boca Raton, while about 24 percent of the original volume was lost from the template at Palm Beach. The difference in magnitude of erosion may be even larger considering that data for Boca Raton was obtained after the passage of Hurricane Frances while the data for Palm Beach was obtained after the passage of Frances and Jeanne (Boca may have eroded even more after Jeanne). Even though Boca Raton was located further away from the storm's eye, it eroded significantly more than Palm Beach. The differential in erosion magnitute may be partially attributed to the time-interval between construction and hurricane landfall, and to the offshore geomorphology. Palm Beach was constructed in January-February 2003 (1.6 years prior to landfall), while Central Boca Raton was constructed in March-April 2004 (only six months prior to landfall). Because of the short interval between construction and hurricane landfall in Boca Raton, a significant part of the volumetric losses and erosion observed in this project may be attributed to project profile and planform adjustment, which was accelerated by these high-energy storms. While there wasn't much time between construction and hurricane landfall at Boca Raton, the Palm beach project had about 1.6 years to adjust prior to the 2004 hurricanes.

The lesser amount of erosion at Palm Beach may also be attributed to nearshore bathymetric features. The high-relief rock outcrops that are located between -10 to -18 foot perch the beach profile and are a barrier to cross-shore sand transport. Additionally the crest of the offshore shore-parallel reefs lies about -40 feet at Palm Beach and about -55 to -60 feet offshore Boca Raton -- thus, wave energy is more efficiently dissipated at Palm Beach). Both features (surf zone rock and offshore reefs) may have contributed to the lesser amount of erosion observed at Palm Beach. Surf zone rock outcrops located at Town of Palm Beach may prohibit onshore sand migration due to its steep seaward slopes. This sand may accumulate in the in-filled sediment trough located between the nearshore rocks and the offshore reefs (see Figure 11).

Offshore sand deposition extended up to -22 feet in Boca Raton and – 30 ft in Town of Palm Beach. These depths are consistent with observation in other papers in this special issue. It must be recognized that closure depth is a function of time-scale (e.g., Capobianco, et al., 2003, Nichols, et al., 1997). The closure induced by major storms (50 year events such as the 2004 hurricane Frances and Jeanne) is expected to differ from the closure induced by average conditions observed within a 5-10 year timeframe (design closure), which is the lifetime of most nourishment projects in southeast Florida.

Sands migrated beyond the rock outcrops at Palm Beach (except for the Hot spot area near FDEP monument R93). Interestingly, profile change analysis indicated that significant amounts of sand did not deposit on top of these high relief rock outcrops. Rock outcrops generally occur from -10 to -18 feet along the project area and some outcrop crest locations are verified in even shallower water (8 feet or less). Wave breaking is commonly observed on top of these rock outcrops when wave heights exceed 6 feet; thus, they are analogous to 'fixed' bar systems. The steep slopes and the high energy conditions commonly observed on and around these surf zone outcrops during high-energy events create an environment that may be not favorable to deposition of fine- to medium-grained sands. This may be the reason why the data collected post-storm indicated that active offshore deposition was observed seaward of the rock outcrops along the Town of Palm Beach project but the rock outcrop per se remained relatively clear of significant sediment deposition that is measurable by bathymetric surveys.

Large alongshore variability in shoreline and volume changes was observed in both projects. While this variability may be linked to nourishment adjustment in Boca Raton it appears to correlate with the location of offshore bathymetric features (shore-parallel reefs, reef gaps, surf-zone outcrops etc.) in Palm Beach. The control exerted by these offshore bathymetric features on shoreline and volume changes may be further investigated to enhance our predictive capabilities of future impacts of high-energy events on nourished beaches.

FINAL CONSIDERATIONS

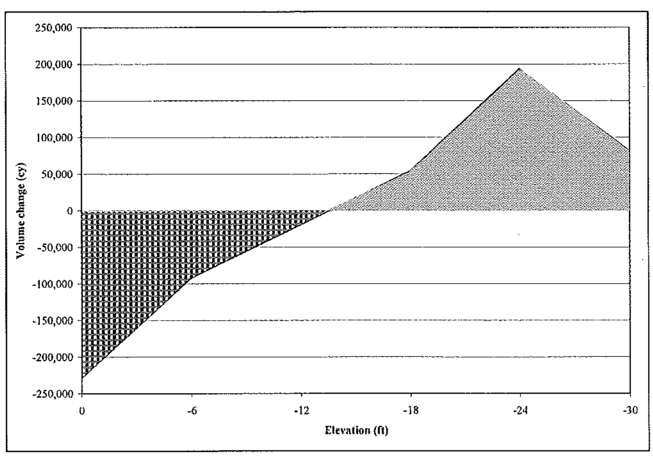

Figure 13. Volume changes along the Town of Palm Beach project area computed per depth interval. Notice that erosion was observed from -12 to -13 feet and deposition was observed from this elevation to -30 feet. The elevation shown as zero actually represents the erosion of the subaerial beach (toe of dune to 0 feet). The peak of erosion was observed at subaerial beach while the peak of deposition was observed around -24 feet deep.

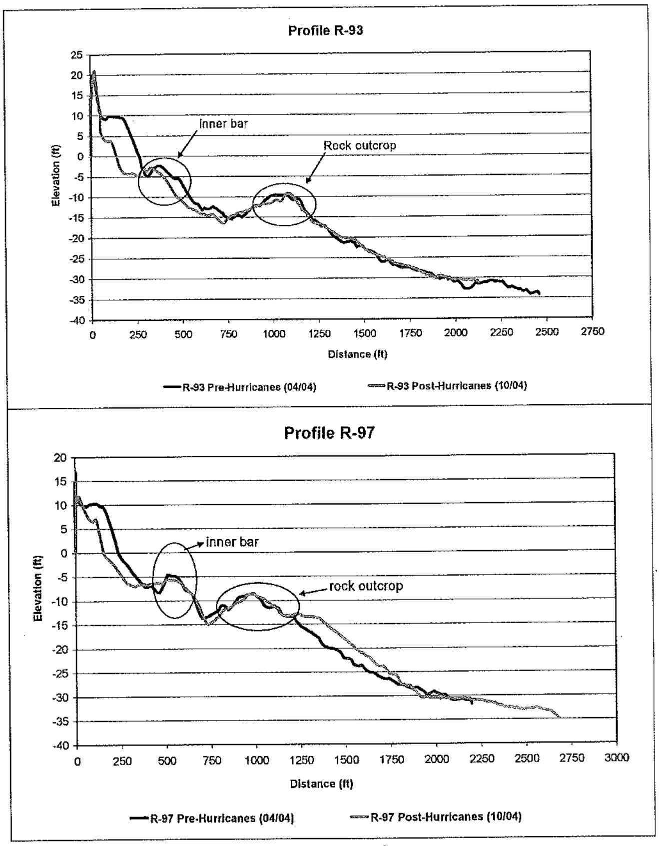

Figure 14. Beach profile changes for two selected monument locations. Changes observed at R-93 (top graphic) include large beach erosion (this was the hot spot area) and no offshore deposition. The inner bar showed a general depression in elevation and a slight onshore migration, while elevations at the surf zone rock outcrops remained unchanged. At R-97 (bottom image) beach erosion of lesser magnitude than R-93 was observed. Little elevation change occurred on the inner bar system at this location and no change in elevation was observed at the surf zone rock outcrops. A large and widespread offshore bar-like feature formed seaward of the rock outcrop between elevations of -14 and -26 feet.

The performance of two nourishment projects located on the southeast Florida Atlantic coast during the 2004 hurricane season was discussed here. Both projects performed well and provided significant storm protection from Hurricane Frances and Jeanne. The damage to landward infrastructure at the nourished beaches was minimal, while non-nourished beaches located a few miles to the north and south of the project areas sustained more damage.

Both projects eroded above the-12 to -13 foot contour, where an inflection point was observed and deposition predominated between -12 to -30 feet contour offshore. The offshore limit of deposition was around -22 ft for Boca Raton and -30 ft for Town of Palm Beach. Although the erosion signature extended up to -13 feet, most of the sand was eroded from the subaerial beach. As a general trend, the erosion of the subaerial beach and inner surf zone eroded was mirrored by an accretion offshore in the form of large storm bar in deeper water (generally between -14 to -26 feet). Erosion from the project templates ranged from 24 percent to 46 percent in Palm Beach and Boca Raton respectively.

Interesting morphological responses closely related to the complex offshore reef system and the presence of high-relief rock outcrops within the surf zone was observed at Palm Beach. The sand eroded from the beach in this event deposited seaward of surf zone rock outcrops, but significant sediment deposition was not measured on top of the outcrops. A deep-water bar was formed between -15 to -26 feet of water in most areas (except for the Hot spot segment). Recovery of this beach may be prohibited by the steep seaward face of these rock outcrops.

The hypotheses raised in this paper to explain the observed performance of these two nourishment projects warrant further investigation. The data sets generated during the 2004 hurricane season for nourished beaches along the southeast United States require further attention because they provide research opportunities on the general subject of beach nourishment response to extreme storms. Research needs identified in this paper include beach recovery magnitudes and time scales, the potential influence of high-relief rock outcrops located within the surf zone on beach response to storms and subsequent recovery, the influence of offshore reef geomorphology on hot spot location along southeast Florida, the time-scale variability of closure depth in southeast Florida, etc. Process-based models may be used to investigate some of these processes.

The coupling of the data presented in this paper with laser bathymetry surveys conducted prior to the hurricanes (e.g., Finkl, et al., 2004) with LIDAR data obtained post-hurricanes by the U.S. Army Corps of Engineers' Jacksonville District in collaboration with the U.S. Geological Survey may be helpful in further describing project performance and morphological response and providing data to calibrate numerical model studies. More detailed analysis of the various performance data acquired and numerical modeling studies would promote a better understanding of the response of nourished beaches during extreme weather events and help the FDEP and consulting companies alike to deal with key environmental permitting issues in the future.

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