THE IMPACT OF HURRICANE ELENA AND TROPICAL STORM JUAN ON COASTAL CONSTRUCTION IN FLORIDA

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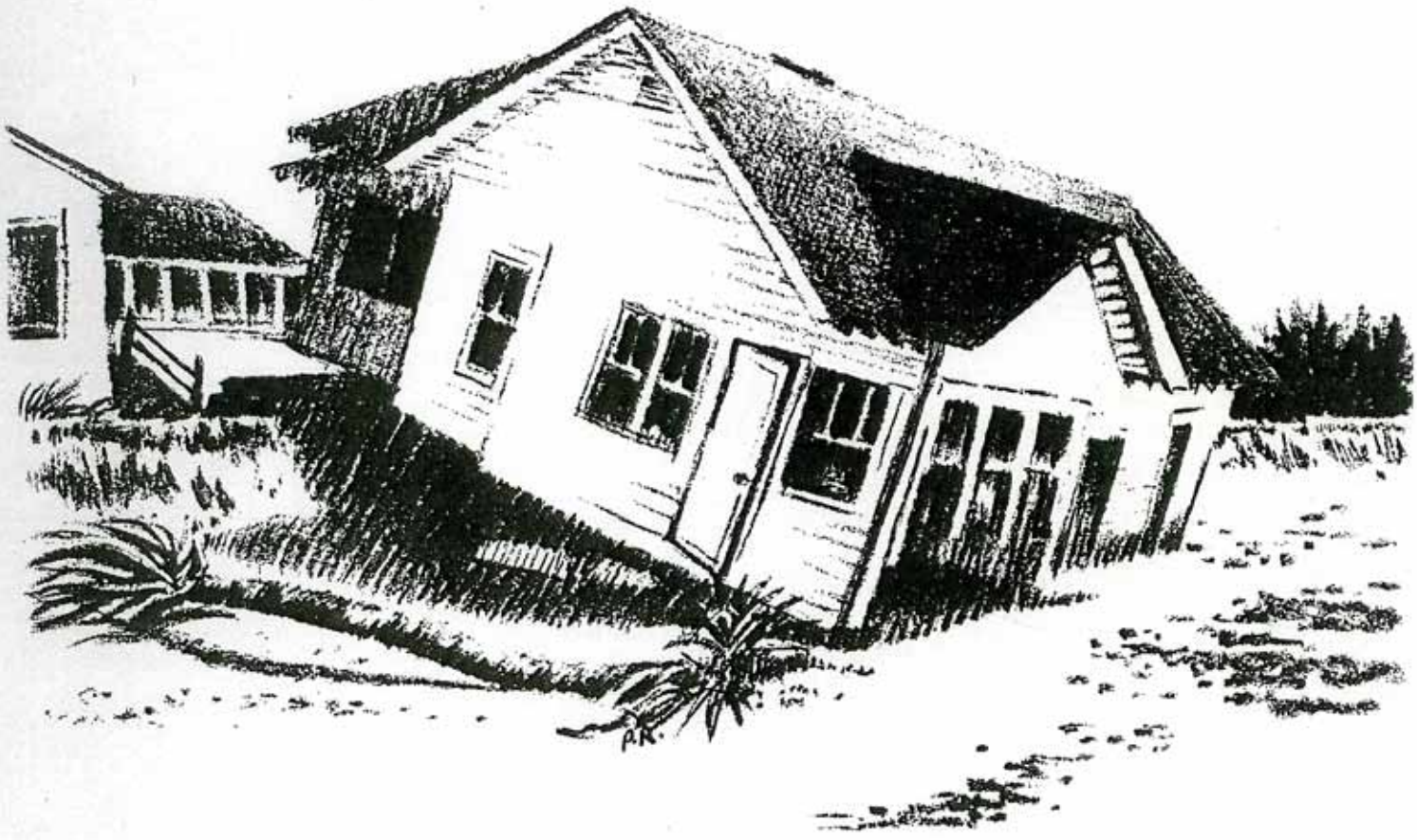

Bureau of Coastal Engineering and Regulation
Division of Beaches and Shores
FLORIDA DEPARTMENT OF NATURAL RESOURCES

FORWARD

This work describes the impact of Hurricane Elena and Tropical Storm Juan on coastal construction in Florida. Contributions of damage information were provided by the following engineers of the Bureau of Coastal Engineering and Regulation, Division of Beaches and Shores: Carlos R. Carrero, James D. Christie, G. L. Hill, John Kea, Michael Joity, Mark E. Leadon, Brett D. Moore, and Steve West. Additional photographic contributions were provided by H. N. Bean, Kevin R. Bodge of the University of Florida, Dave Dodder, G. L. Hill, Michael Joity and Steve West. The manuscript was typed by Sarah C. Papin. Peggy M. Reidell created the cover.

Hurricane Elena and Tropical Storm Juan occurred in 1985.

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INTRODUCTION

The 1985 tropical storm season brought to the Gulf of Mexico coast of Florida two major storms which reached hurricane status prior to landfall of their eyes in the northern Gulf of Mexico coast west of Florida (Figure 1).

Between August 29 and August 30, hurricane Elena traversed the eastern Gulf of Mexico from Cuba heading towards New Orleans, Louisiana, before veering east during the afternoon and evening of August 30 and threatening to landfall at Cedar Key, Florida. After stalling for twenty-four hours offshore from Cedar Key, Elena intensified and reversed its track once again. Between the evening of September 1 and September 2, Elena traversed the northeast Gulf of Mexico on a northwesterly track crossing Dauphin Island, Alabama, and landfalling on the coast of Mississippi where it caused extensive wind damage. The northwesterly track of Elena during the afternoon and evening before Labor Day brought the peak impact of the storm on the coastal barriers of Franklin and Gulf Counties in north Florida. During the stall off Cedar Key and the subsequent intensification, the coastal barriers of Pinellas, Manatee, and Sarasota Counties on the lower Gulf of Mexico coast of Florida, were dealt their greatest impact.

Between October 26 and October 28, hurricane Juan spawned in the southwestern Gulf of Mexico and traversed the western Gulf before landfall of the eye in southwestern Louisiana. The Florida coastline would have been spared the impact of Juan had the storm continued northward and dissipated. Juan stalled and drifted erratically eastward along coastal Louisiana between October 28 and 31 before the eye made a final landfall at Gulf Shores, Alabama. After the Panhandle of Florida was moderately impacted by tropical storm Juan at midday October 31, the lower Gulf coastal barriers of Pinellas, Manatee, Sarasota and Lee counties were continuously impacted by the storm's spiral bands through the evening of Halloween.

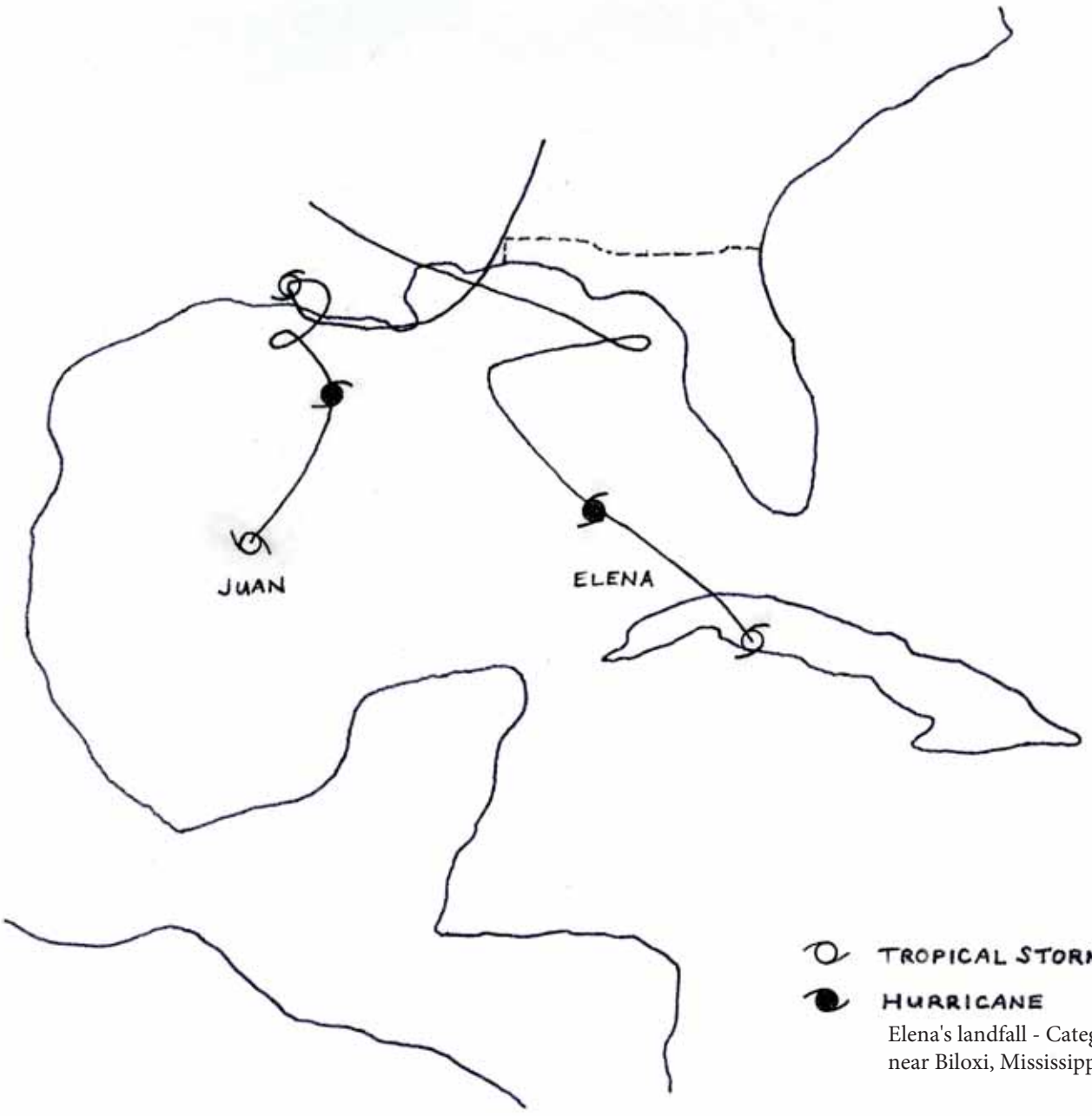
A detailed analysis of hurricane Elena and its erosion impact on the coast of Florida is presented in Beaches and Shores Post Storm Report No. 85-2. No attempt is made in this discussion to quantify the impact of either storm but only to qualitatively discuss both storms' impact on coastal construction based solely upon observations of the damage.

A discussion with accompanying photography is presented by geographical areas commencing in Escambia County and continuing eastward and southward around the Florida coast through Collier County. It is the intent of this report to present only the impact of the storms to the coastal barriers and not to discuss

the damages sustained by severe weather conditions inland of the barrier islands or along the wetland coast of Florida between Franklin and Pinellas Counties. Because of the similarity with the beaches that front directly on the Gulf of Mexico, included will be a discussion of the shoreline damages of St. George Sound and Alligator Harbor. However, no discussion will be made of the dock and bulkhead damage sustained around the other coastal bays and estuaries. Additionally, no attempt will be made to discuss inland flooding or tornado damage although both storms produced severe weather conditions which inflicted major structural damage both in northern and central Florida.

Because of the offshore location of Elena's peak winds and the greater distance to Juan's substantially lower wind velocities, most of the damage to coastal construction was due to the storm tide and wave activity as opposed to the winds. Even though an astute study of the storm's impact should corrolate the proximity, the track, and the intensity of the storms, the most relevant factors affecting the severity of the damage observed were the nature of the construction and the availability of an energy absorbing natural beach and dune system.

Separate general discussion is presented of the damage to major structures and of the damage to rigid coastal protection structures. In conclusion, design guidance is provided for coastal reconstruction in the impacted areas.



Elena's landfall - Category 3
near Biloxi, Mississippi

FIGURE 1. Storm tracks of Elena and Juan in 1985

THE FLORIDA PANHANDLE

As hurricane Elena raced west-northwestward just offshore from the Florida Panhandle one would have suspected a major coastal impact. Such an impact simply did not occur. Once again, when on Halloween, tropical storm Juan crossed Gulf Shores, Alabama, the Florida Panhandle was expected to receive the worst coastal impact of a major storm since hurricane Frederic in 1979. The resulting impact was substantially less than Elena.

On Perdido Key in Escambia County, only minor to moderate beach and dune erosion was sustained during hurricane Elena, and most of the erosion was incurred during the day on August 30 when the storm was initially headed northwesterly toward New Orleans. Although no major structures sustained any major structural damage on Perdido Key, the Vista Del Mar Condominium near the middle of the island was subject to the upper reaches of wave uprush leaving the large building's grade level foundation exposed. This building was the most inappropriately sited of the structures along the Florida stretch of Perdido Key and a dune restoration project to include a core of large hydraulically filled polypropylene sand bags is being constructed to mitigate future storm damage. Tropical storm Juan induced more beach accretion than erosion along Perdido Key.

On Santa Rosa Island which extends from the entrance to Pensacola Bay in Escambia County eastward to the entrance of Choctawhatchee Bay in Okaloosa County, generally minor to moderate beach and dune erosion occurred during Elena. Along the west end of the island, approximately one mile of the two lane asphalt road to Fort Pickens within the National Seashore was destroyed. The storm tide and wave setup was observed to inundate a considerate stretch of the island between Pensacola Beach and Fort Pickens. This area sustained a major loss of the barrier dunes during hurricane Frederic in September, 1979. Although since then, there had been some natural dune accretion with an extensive sand fencing program, during Elena on August 30 the area experienced sustantial rescouring leaving the roadbed extremely vulnerable to future coastal flooding. The elevations in this area range between +5.0 feet +7.0 feet NGVD and the storm tide elevation of Elena was reported to be approximately +7.5 feet NGVD on August 30 (Balsillie, 1985). The area sustained additional flooding during tropical storm Juan on October 31.

Along Pensacola Beach on Santa Rosa Island, approximately 137 feet of the middle of the Pensacola Beach fishing pier was destroyed by Elena. The pier was substantially destroyed in Hurricane Frederic in 1979, rebuilt and damaged again during the "El Niño" extratropical storms in the spring of 1983. A 56 unit concrete building, the Dunes Motel, sustained major damage to 27

units as it experienced substantial undermining following the failure of its 200 foot long concrete retaining wall during Elena on August 30 (Figure 2). Approximately 8,000 cubic yards of sand fill were placed under the building on an emergency basis in 1979 after hurricane Frederic; however, the storm tide and wave uprush from Elena and Juan removed all the fill that was placed. On October 31, the building was substantially undermined by Juan and destroyed by wave action (Figure 3). The Gulf front 27 units were completely destroyed and the road front 29 units were damaged beyond repair.

At Navarre Beach on Santa Rosa Island, approximately 160 feet of the Gulfward end of the Navarre Beach pier was destroyed by Elena. Additionally, a 60-foot section of pier decking landward of the remaining end is sagging because of settlement and damage to a group of supporting piles.

Along the developed areas of Pensacola Beach, Navarre Beach, and Ft. Walton Beach numerous dune walkovers were damaged with the seaward ends destroyed by Elena. Much of the dune accretion since hurricane Frederic was eroded and added to the beach system. Along the National Seashore between Pensacola Beach and Navarre Beach and along Eglin Air Force Base property between Navarre Beach and Ft. Walton Beach, numerous dune breaches created by hurricane Frederic were reopened and flooded by the storm tide of Elena. Isolated heavy dune erosion was also experienced; however, no major structures appear to have been threatened.

Between East Pass in Okaloosa County and Port St. Joe in Gulf County, minor beach and dune erosion was the general rule during Elena with total recovery expected to be rapid. Juan appears to have assisted the recovery in some areas. On Panama City Beach, Juan destroyed 100 feet of concrete bulkhead and 100 feet of concrete retaining wall at the Teasure Island Motel.

Because of the nearness to hurricane Elena moderate to heavy beach and dune erosion occurred along the St. Joseph Peninsula and eastward from Cape San Blas to Indian Pass. Approximately 1,500 feet off the exposed south tip of Cape San Blas disappeared as the hurricane's center passed by approximately 30 miles offshore (Figures 4 and 5). Several tidal channels were formed across the Cape south of the lighthouse beach access was inundated by coastal flooding. While the storm tide elevation was reported to be approximately +7.0 feet NGVD (Balsillie, 1985) there was undoubtedly a substantial head differential of the storm tide from east to west across the Cape and outer shoals as witnessed by the depth and alignment of the scour channels and the flattening of the dune and wetland vegetation covering the Cape. The fishing pier on Indian Peninsula was damaged by Elena. No other major structures on the Gulf County beaches were damaged

by Elena's storm tide or wave activity, although minor wind damage particularly to roofing was widespread. Numerous dune walkovers were destroyed. Juan's effect in this area was limited to additional minor dune erosion losses in the areas of historic high shoreline recession.

Hurricane Elena and Tropical Storm Juan occurred in 1985.

FIGURE 2. Dunes Motel damaged by Elena's erosion, Pensacola Beach (D. Dodder)

FIGURE 3. Dunes Motel destroyed by Juan, Pensacola Beach (G. L. Hill)

FIGURE 4. Cape San Blas, November, 1984 (K. R. Bodge)

FIGURE 5. Cape San Blas, September 3, 1985 (K. R. Bodge)

ST. GEORGE ISLAND AND DOG ISLAND, FRANKLIN COUNTY

During the evening of September 1, hurricane Elena achieved its closest position off the Florida coast, with the center of the eye passing only 36 miles offshore from St. George Island. Unlike a shore incident major hurricane which would have brought with it a large storm surge inundating the island from gulf to bay, the offshore pass of the storm only brought the island a storm tide of +8.0 feet NGVD (Balsillie, 1985). The storm tide would have been considerably greater had the eye hit the island because the storm had intensified to a catagory 3 hurricane with 125 miles per hour maximum sustained winds and a central barametric pressure of 954 millebars (National Weather Service, Apalachicola).

Complete overtopping of the storm tide did occur across the old tidal pass (now closed) which used to separate Little St. George Island from St. George Island. Overtopping also occurred at the center of the island, with the shell road to the west of the St. George Island Causeway receiving substantial hydraulic scour as the storm tide waters were funneled between two existing concrete commercial buildings before entering a marina at the boat ramp. Sheet flow overtopping also occurred at the old closed pass east and west of the entrance to the state park and throughout the eastern three miles of the island within the park. Due to east to southeast wind and wave attack a significant setup of the storm tide occurred on the beach immediately east of the east jetty at the St. George Island Channel. Substantial shoreline recession took place along the east and west shorelines of the channel resulting in a breaching of the inlet's rock jetties (Figures 6 and 7). During high tides following the storm the flood tidal flow transported into the inlet from the outside of the jetties which had become isolated structures. In an emergency maintenance dredging operation after the storm the Mobile District Corps of Engineers removed shoals caused by the hurricane's storm tide and waves and placed the dredge material between the jetties and the shoreline to close the breaches.

Along the entire lengths of St. Vincent Island, Little St. George Island, and St. George Island heavy dune erosion took place because of Elena (Figures 8 and 9). Nearly all the dune walkover structures were destroyed or damaged along St. George Island. Fallen pines and light roof damage was widespread throughout St. George Island; however, there was no major structural damage to any major structures. A few large decks were destroyed and a number of roofs had to be replaced due to the light wind damage, but generally structures faired well. A discussion will follow reflecting the design adequacy and siting as reasons for the success of the major structures in this storm. Tropical storm Juan had very little impact along the island as the storm tide did not even reach the dune line eroded by Elena.

St. George Island State Park sustained the greatest damages on the island during Elena. Among the reasons for this are:
1. The shoreline alignment of the park took incident storm wave attack while the remainder of the island experienced wave attack at a greater angle to the shoreline.
2. The east end of the island like the south point of Cape San Blas had the greater exposure to the storm waves.
3. The average ground elevations along the eastern three miles of the island are very low subjecting the entire area to inundation from the storm tide.
4. The barrier dune elevations along the park are lower than the rest of the island and therefore the horizontal dune recession was greatest.
5. The park road is in close proximity to the beach berm and shoreline in contrast to the remainder of the island's roads. In short, the park is most susceptible to coastal flooding and the shoreline alignment was of greatest exposure to this particular storm.

The park road was destroyed along much of its length in 1972 by hurricane Agnes. Reconstructed by the Florida Department of Transportation in the mid-1970's, the road has performed well for the past decade. Elena totally destroyed approximately 400 feet of the road at its eastern end (Figure 10). An additional 350 feet of the south pavement edge was damaged due to direct wave attack and undermining. Along approximately 20,650 feet or 3.91 miles of the road, the north pavement edge was damaged due to the hydraulic scour by storm surge overtopping. The pavement edge damage rendered this narrow two lane asphalt road unsuitable for safe driving conditions.

The park's beach access facilities sustained major damage to the ten dune walkovers and approximately 500 feet of boardwalk was totally destroyed by Elena. Approximately 1,000 cubic yards of beach sand was deposited on the west beach parking lot and another 500 cubic yards of beach sand was deposited on the east beach parking lot. The picnic facilities, outdoor showers, and bathroom utilities sustained heavy damage and the portable restrooms near the park entrance were destroyed. The park entrance office was also flooded.

Although accurate surveys of the east tip of St. George Island have never been conducted, at least 500 feet of the east tip was observed to be eroded by Elena. Across a wider East Pass, Dog Island sustained heavy dune erosion along its entire length and storm tide overtopping occurred in the two low narrow areas near the island's west end. Widespread roofing and minor wind damage occurred during Elena and one single family dwelling sustained major wind damage to its roof (Figure 11). The community center, a metal building founded on a concrete slab was totally destroyed by undermining and direct wave attack after it collapsed on the

beach (Figure 12). It is not known whether the structure was damaged on August 30 when Elena initially passed offshore; however, following the erosion event of August 30 the building was certainly placed in imminent danger of collapse from further erosion which did occur on September 1 during the second and most devastating of offshore passes. Nearby, the multi-unit Pelican Inn sustained major deck and walkway damage and the concrete block stairwells on the front of the building were destroyed (Figure 13).

FIGURE 6. St. George Island Channel, November, 1984
(K. R. Bodge)

FIGURE 7. St. George Island Channel, September 2, 1985
(H. N. Bean)

FIGURE 8. Dunes eroded by Elena, St. George Island (G. L. Hill)

FIGURE 9. Dunes eroded by Elena, St. George Island (G. L. Hill)

FIGURE 10. Park road segment destroyed by Elena, St. George Island

FIGURE 11. Dwelling damaged by Elena's wind, Dog Island (G. L. Hill)

FIGURE 12. Metal community center destroyed by Elena's waves, Dog Island (G. L. Hill)

FIGURE 13. Pelican Inn damaged by Elena, Dog Island (G. L. Hill)

ST. GEORGE SOUND SHORELINE, FRANKLIN COUNTY

Because of the strong east to southeast winds associated with Elena's west-northwestward track on September 1, a significant setup of the storm tide occurred along the east shoreline of the causeway to St. George Island. Because of this storm tide and the incident storm wave activity which grew over a long fetch length of St. George Sound, major damage to 1,600 feet of the causeway was sustained (Figures 14 and 15). Approximately 830 feet of the concrete bulkhead was destroyed by wave activity and the Intracoastal Waterway bridge abuttment sustained major damage due to hydraulic forces of the storm tide. Although the concrete bridges appear to have sustained no major damage, three bridge approaches were destroyed. The erosion loss to the causeway requiring replacement totaled approximately 58,000 cubic yards of fill (Florida Department of Transportation).

Much of the sandy mainland shoreline along St. George Sound typifies a barrier beach and dune system. There is a high degree of exposure to storm tides and wave activity along the shoreline stretch opposite the open water gap between Alligator Point and Dog Island and adjacent to East Pass between Dog Island and St. George Island. Along a 10 to 12 mile stretch of U. S. Highway 98, the two lane asphalt road is located in close proximity to the shoreline along a considerable distance. Although the shoreline length of damaged road was not determined, after Elena the Florida Department of Transportation measured 123,000 square feet of pavement destroyed and 130,000 cubic yards of fill lost from U.S. Highway 98 (Figures 16 and 17).

The Carrabelle Beach area west of Carrabelle is directly exposed to the storm tide and wave activity through East Pass between Dog Island and St. George Island. East Pass is approximately two miles wide and the four miles of shoreline immediately adjacent to East Pass sustained moderate to heavy beach and dune erosion. Along this stretch of shoreline seven single-family dwellings were destroyed and two more single-family dwellings sustained major damage due to the storm tide, erosion, and wave activity (Figures 18 through 21). Inadequate foundation design and inappropriate siting were the primary reasons for the damage to these structures.

Along the shoreline near Lanark, adjacent the open water expanse between Dog Island and Alligator Point, one wood framed single-family dwelling was destroyed (Figure 22). This structure was not inappropriately sited because its location was a couple hundred feet from the shoreline in an upland stand of pines; however, the structure was not sufficiently elevated and it sustained heavy damage from the storm tide and direct wave activity.

At the Lanark Marina, the storm tide and wave activity from Elena carried the floating docks and a few boats across the crown of U.S. Highway 98 and placed them in the ditch along the north right-of-way (Figure 23). The crown elevation of the road was measured at +7.487 feet NVGD by the survey team of the Bureau of Coastal Data Acquisition, Division of Beaches and Shores.

FIGURE 14. St. George Island causeway damaged by Elena's waves

FIGURE 15. St. George Island causeway damaged by Elena's waves

FIGURE 16. U.S. Highway 98 damaged by Elena, Carrabelle Beach

FIGURE 17. U.S. Highway 98 damaged by Elena

FIGURE 18. Carrabelle Beach after Elena

FIGURE 19. Carrabelle Beach dwelling destroyed by Elena

FIGURE 20. Carrabelle Beach dwelling destroyed by Elena

FIGURE 21. Carrabelle Beach dwelling destroyed by Elena

FIGURE 22. Lanark dwelling destroyed by Elena

FIGURE 23. Elena's flooding at Lanark Marina, U.S. 98

ALLIGATOR POINT TO OCHLOCKONEE BAY ENTRANCE, FRANKLIN COUNTY

The easternmost coastal barrier shoreline in Franklin County includes the four mile long peninsula of Alligator Point between its northwest tip and the Southwest Cape, the two mile eroding beach between the Southwest Cape and Lighthouse Point, and the three mile long low energy beach between Lighthouse Point and Bald Point at the entrance to the Ochlockonee Bay. With the inclusion of the Alligator Harbor shoreline of Alligator Point, this stretch of sandy shoreline includes all possible shoreline alignments for exposure during all storm conditions. For those areas fronting on the Gulf of Mexico, there are three areas of significant shoreline erosion stress: the Phipps Preserve on the northwest tip of Alligator Point, the one mile stretch of shoreline east of the Southwest Cape, and the one mile stretch around Lighthouse Point.

In 1972, hurricane Agnes destroyed a few single-family dwellings near the Southwest Cape and several others sustained major damage. At the northwest tip of Alligator Point nearly all the single-family dwellings were destroyed or sustained major damage. Extratropical storms in January, 1978, March-May, 1983, and March, 1985, caused substantial continued erosion stress to the areas of critical erosion. Not surprisingly, hurricane Elena dealt its greatest erosion impact to these same areas. In the erosion stress areas moderate to heavy dune erosion occurred, yet in the areas not subject to continued erosion stress only minor beach and dune erosion was observed although significant damage to the beach/dune vegetation was seen. The vegetation damage, as well as, the erosion in the non-stress areas is expected to substantially recover within a year's growing cycle provided additional major storms do not impact the area.

The 4,000 feet of the Phipps Preserve along the northwest tip of Alligator Point was inundated by a storm tide of approximately +8.0 feet NGVD (personal observation). The wave wash and hydraulic velocities of the storm tide across this low spit of sand must have been substantial, because about one hundred wire cage crab traps with their buoy lines attached and most filled with crabs were randomly scattered all across the Phipps Preserve.

The rock groin field to the east of the Phipps Preserve provided adequate protection to the adjacent shoreline properties. The 100 foot long western groin which became detached from the shoreline in the extratropical storm of January 19, 1978, was completely destroyed by Elena. Along the four miles of the peninsula widespread minor roofing damage and other light wind damages were sustained to single-family dwellings. Minor water damage was also inflicted on a few grade level beach houses along

During August 30-31, strong north winds and high tides inflicted damage along the Alligator Harbor shoreline of Alligator Point. Two single-family dwellings sustained major damage and the Franklin County Road C370 was threatened by erosion conditions at three bayshore locations. On September 1, approximately 800 feet of the road was damaged at these three bayshore locations; 300 feet were landward of the coastal construction control line and 500 feet were seaward of the control line. The same two bayshore dwellings sustained even greater wave induced damage on September 1, and a boat shed nearby was destroyed (Figure 24). While the eye of Elena stalled off Cedar Key gale force north winds peeled most of the roofing off a couple beach houses along the peninsula and blew the southeast wall out of an open garage causing the entire garage roof to collapse. While the shoreline to the west of the Southwest Cape has been historically stable, the shoreline for approximately one mile to the east has experienced considerable erosion stress. Isolated dune bluff recession of ten to fifty feet has been witnessed in extratropical storms during the past decade at the Southwest Cape. Several dwellings have been relocated as far landward as possible during this period and revetments and bulkheads have been constructed as a final effort to protect the upland properties against continued storm induced erosion.

Along Chip Morrison Drive, a few dwellings immediately east of the Southwest Cape were placed in imminent danger and were in need of being relocated inland. Heavy dune erosion from Elena nearly reached these slab-on-grade structures (Figures 25 and 26). Between 500 and 800 feet east of the southwest Cape, a 300 foot long rock revetment was constructed to protect three dwellings after the "El Niño" extratropical storms inflicted heavy dune erosion in the spring of 1983. This stretch of revetment was authorized by the Department of Natural Resources and most of it was constructed to the Department's engineering recommendations. The eastern eighty feet and western eighty feet of this revetment was damaged primarily because of flanking around the ends of the structure which did not have sufficient returns into the upland. It had been anticipated that the revetment would continue both westward to stable shoreline conditions and eastward 200 feet to an existing rock revetment. The western end damage was also due to the low crest elevation and storm wave overtopping which caused substantial erosion losses behind the structure as well as around the end.

A pile-supported single-family dwelling immediately east of the Chip Morrison Drive revetment was totally destroyed on September 1. On August 31, the foundation pile tips of this dwelling were observed to be nearly exposed due to the erosion inflicted by Elena's first pass. The inadequate foundation piles were obviously knocked out by the storm waves. The superstructure collapsed on the beach and the storm waves completely demolished

the structure leaving it in one compact heap of wood, furniture and fixtures (Figure 27). The next single-family dwelling to the east was left in imminent danger of collapse even though it remained standing after the storm. Additional piling supports are needed, regardless of whether a revetment is constructed at the site.

A sixty foot long rock revement to the immediate east was totally destroyed by Elena on August 30, and an inspection of the dwelling behind it on August 31 raised the expectation that it was on a slab and would soon be destroyed. The dwelling was completely undermined on September 1 allowing an inspection of short wood piles which supported the slab and the old house with no major damage (Figure 28). The revetment had been constructed in the mid-1970's and contrary to the engineering recommendations of the Department the rock was not placed on a filter fabric to prevent settlement. Further to the east about 200 feet, a 100 foot long vertical concrete bulkhead was completely destroyed by Elena on September 1, but the dwelling was adequately supported on a pile foundation and was not damaged (Figure 29).

On August 31 after Elena's first pass and on September 2 after the final impact of the storm, inspections were made of the Franklin County Road C370 fronting the KOA Campgrounds. This stretch of shoreline was impacted by all the previously mentioned major storms since hurricane Agnes in 1972, but the dumping of concrete and asphalt rubble debris and small rocks by the Department of Transportation in the 1970's and by the county road maintenance staff in the 1980's along with substantial quantities of clean sand fill since 1983, has provided this critical evacuation route with its only protection. The spring of 1985 brought the completion of a Mobile District Corps of Engineers study which resulted in the design of a rock revetment similar to the structure previously authorized to the Florida Department of Transportation in the early 1970's and not built, and similar to the structure recommended by the author to the Franklin County Commissioners in the spring of 1983. The County did not construct the revetment during the summer of 1985. On August 30-31 the road sustained major damage along approximately 1,000 feet with the seaward lane of asphalt pavement being undermined and collapsing back to the road centerline (Figures 30). On September 1, approximately 1,700 feet of the two lane asphalt road was completely destroyed (Figure 31). In September, the County proceeded with the replacement of an emergency roadbed which was completed in October.

East of the KOA Campgrounds, four pile supported single-family dwellings sustained only light damages as their septic systems, stairways, and utilities were substantially damaged (Figures 32 and 33). One dwelling's fiberglass septic tank was transported approximately 250 feet westward before being deposited along the

roadbed. The entire remaining barrier dune seaward of the road was destroyed for 1,400 feet east of the campgrounds; however, the shoreline position actually advanced as the beach accreted with the additional sand eroded from the dune.

On August 30, at a location 350 feet east of the four pile supported dwellings, a 100 foot long wood bulkhead fronting a dwelling was destroyed and the entire yard seaward of the house was lost to erosion (Figure 34). An inspection of the dwelling on August 31 revealed initial major damage to the front of the structure as the slab had been undermined by several feet. On September 1, the house and its detached garage structure were completely destroyed (Figure 35).

About 200 feet further east, September 1 brought the destruction and major damage to four single-family dwellings. These dwellings were not damaged on August 30 (Figure 36). All four dwellings were constructed on soil bearing foundations. The first dwelling was a concrete block structure on a concrete slab and it was totally destroyed by wave activity (Figure 37). The second dwelling was a wood frame structure on a shallow footing foundation and it settled and sustained major damage to the front wall by wave activity (Figure 38). The third dwelling, a grade level wood frame structure, settled and sustained major wave induced damage (Figure 39). A rock revetment had been authorized to protect the house, but it was not constructed before Elena's impact. The fourth dwelling, a concrete block structure on a slab, sustained heavy wave damage even though it was substantially protected by a partially completed rock revetment (Figure 40). This 80 feet of incomplete revetment sustained moderate damage. Of the adjacent 180 foot long rock revetment to the east, only the western 10 feet sustained damage. To the east of that revetment, 170 feet of wood bulkhead was destroyed but the pile supported dwellings were undamaged.

Moderate to heavy dune erosion was sustained eastward to Lighthouse Point. Immediately west of Lighthouse Point the dune recession nearly undermined one dwelling which should have been relocated inland (Figure 41). To its east, a wood frame dwelling on short wood piles and concrete footings, was undermined and sustained major damage to the foundation and floor slab (Figure 42). An inspection of the structure on August 31 revealed the dune recession had reached to within a couple feet of the dwelling overnight, and on September 1 the continued dune recession caused the eventual damage.

As was the case with the stretch of Franklin County Road C370 fronting the KOA Campgrounds, the stretch of road east of Lighthouse Point has experienced the continued impact of all the recent major storms in the area. An inspection of the road on August 31 revealed approximately 2,000 feet of the road had been

damaged, with the seaward lane and road shoulder being destroyed (Figures 44 and 46). A few hundred feet of concrete bulkhead had also been destroyed by Elena's first pass. On September 1, approximately 2,250 feet of the road was totally destroyed along with 1,400 feet of concrete bulkhead (Figures 45 and 47).

Approximately 10,000 feet northeast of Lighthouse Point, a concrete block, slab-on-grade dwelling sustained major damage due to direct wave attack on the seawardmost projecting wall (Figure 43). No other major damage was incurred along the three mile stretch of low energy sandy beach between Lighthouse Point and Bald Point at the entrance to Ochlockonee Bay. The Coastal and Oceanographic Engineering Department, University of Florida, measured a storm tide in this area of +9.0 feet NGVD.

FIGURE 24. Alligator Harbor shoreline dwelling damaged by Elena

FIGURE 25. Dune erosion by Elena at the Southwest Cape

FIGURE 26. Southwest Cape dwelling threatened by Elena's erosion

FIGURE 27. Southwest Cape dwelling destroyed by Elena

FIGURE 28. Southwest Cape revetment destroyed and dwelling undermined

FIGURE 29. Southwest Cape bulkhead destroyed by Elena's waves

FIGURE 30. Elena's first pass damaged County Road C370 on August 30

FIGURE 31. Elena's second pass destroyed County Road C370 on September 1

FIGURE 32. Elena erosion and damage

FIGURE 33. Elena erosion and damage

FIGURE 34. Wood bulkhead destroyed and dwelling undermined on August 30 (H. N. Bean)

FIGURE 35. Same dwelling destroyed by Elena's erosion and waves on September 1

FIGURE 36. Erosion of Elena's first pass on August 30 (H. N. Bean)

FIGURE 37. Concrete block dwelling destroyed on September 1

FIGURE 38. Frame dwelling substantially damaged on September 1

FIGURE 39. Frame dwelling damaged on September 1

FIGURE 40. Concrete block dwelling damaged by Elena

FIGURE 41. Lighthouse Point dwelling threatened by Elena's erosion

FIGURE 42. Lighthouse Point dwelling damaged by Elena's erosion

FIGURE 43. Elena's waves damaged dwelling near Bald Point

FIGURE 44. Lighthouse Point road damaged on August 30

FIGURE 45. Lighthouse Point road destroyed on September 1

FIGURE 46. Lighthouse Point road damaged on August 30

FIGURE 47. Lighthouse Point road destroyed on September 1

Across the entrance to Ocklockonee Bay, the Trade Winds Pier was damaged and the pier house building sustained major damage from Elena. Mashes Sands, Shell Point, and Live Oak Island sustained minor beach erosion and flooding but no other major damage was in evidence from Elena. Juan had very little impact in this area.

Had Elena continued across the Florida peninsula on August 31, the Cedar Keys of Levy County would have experienced extreme devastation. However, Elena stalled offshore for twenty-four hours on August 31 and September 1 before reversing its course and heading westward. The outer islands of the Cedar Keys, specifically Seahorse Key and Snake Key, incurred heavy beach and dune erosion. On the main island, the City of Cedar Key sustained heavy waterfront damage. The island was substantially flooded and approximately 1,000 feet of the State Road 24 causeway to the mainland was damaged by the hydraulic scour of the storm tide.

The wave activity from the southeast was particularly damaging along the southeast waterfront of the city. At the end of Street between the city park and the boat ramp approximately 115 feet of concrete bulkhead was destroyed and another 240 feet of bulkhead sustained major damage. The pile supported Seabreeze Restuarant and a pile supported dwelling extending seaward of the bulkhead over the main ship channel sustained heavy damage from both the wave uplift forces and the lateral wave loads against the structures. A couple newer adjacent structures constructed at higher elevations sustained no major damage, but two fishing piers were substantially destroyed.

Along 1st Street, two motel buildings at the Gulf View Motel sustained damage from waves and flooding. A pile supported dwelling over the water and six dwellings on the upland sustained damage. A mobile home on 1st Street was destroyed and approximately 500 feet of the west end of 1st Street was damaged. Near the causeway to the mainland the Sunset Isle Trailer Park sustained flood damage. One mobile home was destroyed, one travel trailer was destroyed, one mobile home was damaged beyond repair, and six others sustained lesser damages.

ANCLOTE KEY, HONEYMOON ISLAND, CALADESI ISLAND, AND CLEARWATER BEACH ISLAND, PINELLAS COUNTY

An aerial reconnaissance flight was made on September 3 after Elena's influence on the Gulf coast of Pinellas County. No major damage to major structures was in evidence on the generally undeveloped northern barrier islands of Pinellas County.

On Anclote Key, heavy beach and dune erosion was caused by Hurricane Elena. The emergent shoals between Anclote Key and Honeymoon Island underwent significant morphological changes due to wave activity and overtopping; however, these areas are generally uncharted and there exists no monitoring data for any historical comparison.

The northern spit of Honeymoon Island was breached forming a small tidal inlet near its confluence with the main vegetated portion of the island (Figure 48). It is doubtful that this inlet will remain open for very long. The central portion of Honeymoon Island which exhibits the characteristics of a cobble stone shoreline experienced no significant shoreline recession; however, most of the remaining sand from this former dredge spoil site was completely eroded from the shoreline leaving predominantly small rocks. This rocky shoreline is in critical need of beach nourishment to meet the recreational needs of this area. Although no major structures incurred structural damage at the Honeymoon Island State Recreation Area, the Division of Recreation and Parks reported the light wind damages to roof and exteriors of the park facilities to total $33,250. The southern one-third of Honeymoon Island has generally been accreting and although there was no significant erosion in evidence after Elena or Juan, the area was substantially flooded.

On the north end of Caladesi Island a major inlet breakthrough has occurred (Figure 49). Its location is about 3,000 feet south of the island's north tip at Hurricane Pass and is immediately north of a cuspate foreland called Lone Oak Point. The new inlet is a repeat of the earlier event in October, 1921, when Hurricane Pass was created and separated Honeymoon and Caladesi Islands (formerly North Hog Island and South Hog Island). Unlike the closure expected of the spit breakthrough on Honeymoon Island, this Caladesi Island breach is expected to remain open and perhaps grow larger and probably have a significant impact on the shoaling and hydraulic tidal prism of Hurricane Pass. The remnant barrier island between this new unnamed inlet and Hurricane Pass experienced heavy erosion of its south end and accretion along its north end.

The remainder of Caladesi Island's Gulf front experienced flooding and moderate to heavy beach and dune erosion. The

island's shoreline within Dunedin Pass continues to erode as both Elena and Juan accelerated the inlet's northward migration. The Mandalay Point area to the south of the present channel of Dunedin Pass was overtopped and denuded of vegetation for approximately 2,000 feet. This area has historically been accreting northward with the migration of Dunedin Pass although major storms have caused occasional breaches during the past two decades.

To the south of Dunedin Pass, Clearwater Beach Island is heavily developed with a blend of residential, commercial and recreational beach areas. The northern one mile of the island has a wide beach which varies in width between 200 and 400 feet. Only minor beach erosion was in evidence due to the wave uprush and overtopping of the storms. There may actually have been net accretion in this area; however, no beach profiles were taken in this area after the storms for verification. There was no damage to any major structures seen in this northern stretch of the island. This lack of damage was probably due to the protection afforded by the wave energy absorbing beach.

The central one mile of Clearwater Beach Island is residential and bulkheaded. There is also an unmaintained continuous groin field along this stretch with at least 27 damaged concrete panel groins exposed. The beach width generally varies between 75 feet to no beach at all. Adjacent to the Mandalay Shores Apartments, 20 to 30 feet of the end of the 200 foot long concrete pile/wood deck pier was destroyed by Elena. The half mile south of the pier generally has no beach. This stretch experienced substantial wave overtopping. Although there was no major structural damage to habitable major structures in this area, damage to such minor structures as decks, gazebos, porches, stairways, fences, privacy walls, splash walls, planters, and sidewalks was widespread. The National Ocean Survey tide gage at Clearwater Pass reported a tide of less than +5.0 feet NGVD; however, the storm wave overtopping influenced dramatically higher water levels in this central stretch of Clearwater Beach Island. The water line inside an interior room of a Gulf front residence at 848 Eldorado Avenue reflected a static water level of +9.5 feet NGVD or almost double the reported tidal elevation. Although substantially impacted, none of the walls in this area were destroyed. Only cap damage was in evidence but either revetment construction or beach nourishment is urgently needed to prevent a major catastrophe in this area during a future major storm.

The south one mile of Clearwater Beach Island is developed with predominantly commercial structures and recreational facilities. The beach is wide, varying between 200 and 400 feet in width. There may have been minor deflation of the beach profile in this area as witnessed by the loss of some minor dune areas developed

by the City's sand fencing program; however, the beach actually appeared to have experienced a seaward advancement of the shoreline position. Two beach profiles obtained by the survey team of the Bureau of Coastal Data Acquisition, Division of Beaches and Shores in mid-October, 1985 reflected a shoreline advancement of approximately 90 feet when compared to profiles obtained in October 1974. This data is not meaningful in describing the impact of Elena because the early set of profiles were taken too long ago to represent a prestorm condition and the post-storm profiles were taken six weeks after the storm and therefore represented a recovered profile and not an eroded profile. Irregardless of the invalidity of this data in representing the effect of Elena, the beach is obviously not undergoing any erosion stress.

None of the upland major structures in this area experienced any major damage and this popular recreation area was "back to normal" within a couple days of cleanup after Elena. While the wide recreation beach provided adequate storm protection to the upland structures, the 900 foot long Clearwater Beach pier sustained isolated major damage. A 35 foot long lateral deck section was completely destroyed next to the pier house and entrance gate and the concrete deck in the area of wave peaking at the seaward slope of the outer sand bar was damaged. Wave uplift forces in this area of the pier knocked out one concrete deck slab.

Inside Clearwater Pass, a half mile of the island was significantly impacted by storm waves propagating across the inlet's deep waters. The hotel structures along the inlet shoreline sustained no major damage but at least 300 feet of concrete wall sustained minor structural damage. The concrete pool deck area at the Adams Mark Caribbean Gulf Resort was destroyed and although it was recommended that they replace the damaged structures with a wood post supported segmented deck and containerize the fill between the pool and the wall to prevent a future reoccurrance of the damage, they replaced the deck with the original inferior design. Extensive damage to the asphalt parking area occurred at the Gulfview Holiday Inn due to Elena's storm waves overtopping the concrete bulkhead. The Holiday Inn's bulkhead sustained 120 feet of cap damage. Immediately after Elena, urgently needed revetment construction proceeded along this bulkheaded shoreline and plans have been made for the construction of a series of groins to retain the beach next to the Clearwater Pass bridge.

FIGURE 48. Inlet breach on Honeymoon Island

FIGURE 49. Major inlet breakthrough on Caladesi Island

NORTH SAND KEY, PINELLAS COUNTY

The Florida coastal area receiving the greatest impact from Elena and Juan in terms of damage to coastal structures was the fourteen mile long Sand Key in Pinellas County. Generally, the northernmost two miles and the southernmost three miles, areas with a relatively wide beach, sustained light damage, while the middle two-thirds of the island with very narrow beach sustained heavy structural damage from storm wave activity.

Upon stalling off Cedar Key for twenty-four hours on August 31 and intensifying during the evening and into the morning of September 1, Elena impacted the coast of Pinellas County with a continuum of southwest wind generated storm waves. Along northern Sand Key the damage and erosion clearly evidenced a predominate southwest angle of wave approach. Again, during Halloween Eve, Juan's vast circulation brought a southwest wind generated storm wave activity along the Pinellas County shoreline.

The 2,962 foot long jetty on the north end of Sand Key was constructed in 1975 as part of the Clearwater Pass stabilization project. With the southwest wave activity from both Elena and Juan, sand was transported northward and accreted at the north end of the island. At the Pinellas County Park on the north end of Sand Key up to two feet of sand accreted vertically in the parking area.

Between February, 1981 and June, 1984 an estimated 650,000 cubic yards of sand dredged from Clearwater Pass was deposited along the north 10,000 feet of Sand Key. Although this beach restoration project was not surveyed immediately after either Elena or Juan, five profile stations were established by the Coastal and Oceanographic Engineering Department, University of Florida and a number of sets of profiles were obtained to monitor the beach profile changes during the recovery period after Elena.

In the report of results of this post-storm profile recovery investigation Kevin R. Bodge and David L. Kriebel (October, 1985) describe an initial rapid shoreward transport of beach sand between September 2 and September 3 and then a long slow recovery process after September 3. Bar formation during the adjustment to a storm beach profile is a well known phenomena and a prominent nearshore bar formed along the entire study area due to Elena (Figure 50). The continued accretion of this bar as described by Bodge and Kriebel in the post-storm recovery process brings further awareness to the fact that variable storm tide levels, wave conditions, beach material characteristics, and natural or nourished beach profiles, all contribute to the differences in beach recovery witnessed after different storms around our shoreline.

During storm subsidence, the continued higher wave energy conditions at lower water levels could promote sustantial shoreward sediment transport as was measured during September 2 and September 3. Afterwards the low energy wave conditions moved very little sediment and the normal tide elevations were not sufficient to overtop the storm wave built bar to transport bar sediment landward. During the week of Halloween the wave activity of Juan on generally lower storm tide levels transported substantial quantities of sediment shoreward from the prior storm-built bar.

Bodge and Kriebel calculated an approximate seven percent loss of the initial beach nourishment volume in the area monitored based on profiles between November, 1984 and September, 1985. Although it is not known how much was due to Elena, no other major storm event occurred during this period and the data represents the best available erosion measurements from Elena on northern Sand Key. The data also compares the storm profile adjustment with and without the influence of a vertical wall. The increased erosion of the beach due to wave activity on a vertical wall was measured (Figure 51). This phenomena and recommended solutions to the resulting problems will be discussed in a followup discussion on "Guidance for Reconstruction".

FIGURE 50. Storm beach profile, North Sand Key

FIGURE 51. Scoured beach adjacent vertical bulkhead

BELLEAIR BEACH, PINELLAS COUNTY

Immediately south of the Sand Key beach restoration project is the City of Belleair Beach with a shoreline length of 4,610 feet (0.87 mile). The entire length of Belleair Beach was bulkheaded and the beach berm width prior to Elena varied from about ten feet at the north end to about fifty feet at the south end of the city.

Immediately following Elena, very little beach berm existed at high tide. Bulkheads were substantially damaged or destroyed along 2,190 feet or nearly one-half of the city's shoreline length. Where bulkheads remained standing, a deep scour trough existed to illustrate the wave energy reflective nature of vertical walls and to punctuate the critical need for toe-scour protection in front of the walls. Immediately offshore from the scour trough existed a storm wave built bar with a crest height above mean high water located approximately fifty feet seaward of the walls. Periodic breaches existed in the bar as miniature examples of tidal inlets between coastal barriers. Where bulkheads had failed and waves eroded the barrier dune sediments behind the walls, a beach resulted from the accretion of this additional sediment and approximated a more natural sloping storm beach profile.

Figure 52 shows the exposure of the toe-scour protection in front of the concrete bulkhead at the Montmarte Apartments at the north end of Belleair Beach following Elena. There was no structural damage to the bulkhead or upland property sustained during Elena. Figure 53 reflects the shoreline conditions after one month of post-storm recovery. It took approximately three weeks for the beach to accrete over the rocks to a pre-storm condition. Figure 54, taken immediately after the impact of Juan, shows the beach profile had once again eroded exposing the rock which once again adequately protected the bulkhead and property against storm wave damage. The beach profile subsequently recovered again after Juan.

Immediately south of the Montmarte Apartments a 150 foot long vertical concrete wall at the Nautical Watch property was substantially damaged. This wall extended about twenty feet seaward of the adjacent walls. To the south for 500 feet exists an undamaged sloping concrete block revetment seaward of a vertical concrete bulkhead. The next 200 feet to the south is the Carriage House property where Elena substantially damaged 150 feet of the concrete bulkhead and Juan destroyed 100 feet of that portion which was previously damaged and also undermined and damaged the building. To the south of the Carriage House, the 400 foot long bulkhead and concrete block revetment at the Gulf Belleair sustained no major damage. This wall was overtopped by

both storms and the property lost some fill between the wall and the building. Containerizing the fill between the building and the wall would prevent a reoccurring loss of fill during most future storms which may be anticipated.

To the south of the Gulf Belleair is the Sandbar and Ships Inn property which has a 160 foot long concrete bulkhead with a lower cap elevation than the other walls in the area. This wall was damaged but did not collapse, although it was substantially overtopped by storm waves. The end unit of the grade level concrete block Sandbar Motel which extends seaward of the coastal construction control line was substantially damaged by wave impact loads of Elena. This wall which projects fifteen feet seaward of the adjoining walls is to be cut off to a lower elevation and a new bulkhead is to be constructed on an alignment connecting the adjoining walls. Between the new and old walls is to be constructed a rock revetment.

Immediately to the south at the Serena del Sol was the failure of a 320 foot long concrete block revetment seaward of a concrete bulkhead. Storm wave activity from Elena destroyed this revetment, damaged the cap to the bulkhead, and removed a couple feet of fill vertically from behind the wall. The building received minor undermining along its seaward face and sustained some minor direct wave damage to the front of the lower floor area. The property was left in critical need of a rock revetment seaward of the bulkhead and in need of containerizing the fill between the bulkhead and the building.

South of the Serena del Sol, a 410 foot long concrete bulkhead was destroyed by Elena (Figure 55). A townhouse building at the north end sustained damage and the next three single-family dwelling structures were heavily damaged or destroyed by direct wave action from Elena (Figure 56). Also destroyed by Elena was a swimming pool in front of the Chateau Motel (Figure 57). The south eighty feet of this destroyed wall is the Belleair Beach access at Morgan Street. Juan caused even greater losses at this site which is in critical need of a continuous bulkhead with toe scour protection connecting the Serena del Sol bulkhead with the Tortugas Condominium bulkhead on a straight alignment.

South of the Belleair Beach access is the Tortugas Condominium which had its 400 foot long bulkhead destroyed by Elena leaving only a short north and south segment of wall standing (Figure 58). This wall had some of the best design features of the walls in the area; however, because of the lack of containment of backfill the wall collapsed. It collapsed outward because the wall's tiebacks were concrete encased and therefore designed for compressive loads associated with wave impact loading but the lack of fill containment allowed the deadmen to pull out. This wall had only strips of filter fabric behind its seams where the

concrete panels interconnect (Figure 59). Behind the wall a substantial quantity of the barrier dune sediments were lost and the balconies and seaward face of the concrete buildings were damaged due to undermining (Figure 58). Prior to Juan, emergency measures were taken with rubble mound construction, backfill, and temporary building supports, and no additional major damage occurred.

South of the Tortugas is the condominium, La Casa de los Caracoles, which had its 500 foot long bulkhead substantially damaged or destroyed by Elena (Figure 60). All the seaward building units were undermined and one two-unit structure was destroyed (Figure 61). As occurred at Tortugas, a substantial quantity of the barrier dune sediments were lost from behind the wall. Large grout-filled bags were aligned in the gaps between the remnant standing wall sections after Elena and no further major damage was attributable to Juan.

South of Los Caracoles, the north 60 feet of concrete bulkhead at the Almenaro Condominum was destroyed, the property was eroded up to the building, and the swimming pool was threatened from undermining behind the standing wall along the south half of the property. Although overtopped by Elena's storm waves, the 175 foot long bulkhead at the Sol y Sombra property was not seriously damaged. Toe-scour protection and containerization of clean sand backfill is in critical need along this and the remaining properties of Belleair Beach. South of Sol y Sombra, Elena left breaks in the wall of fifteen feet at La Concha and twelve feet and two of eighty feet at the Aldea Condominium. A swimming pool was also destroyed at the Aldea Condominium.

Adjacent to the Aldea Condominium, the north end of the wall at the Belleair Beach Motel was substantially damaged by Elena. The remainder of this 200 foot long bulkhead is cracked and in critical need of replacement and toe-scour protection. There was a substantial loss of the dune sediments behind the wall and the building was undermined. Inappropriately, the property owner backfilled after the storm with a black dirt which will not only erode more easily but will not have the proper drainage qualities to relieve the back pressure on the wall. Less backfill was placed at the Sonrisa, the southernmost property in Belleair Beach, and only minor damage was sustained by its 200 foot bulkhead.

FIGURE 52. Beach erosion due to Elena at Montmarte Apartments

FIGURE 53. Post-Elena beach recovery after one month

FIGURE 54. Beach erosion due to Juan at Montmarte Apartments

FIGURE 55. Concrete bulkhead destroyed by Elena, Belleair Beach

FIGURE 56. Belleair Beach dwellings destroyed by Elena

FIGURE 57. Bulkhead and swimming pool destroyed Chateau Motel, Belleair Beach

FIGURE 58. Tortugas Condominium bulkhead destroyed and buildings damaged

FIGURE 59. Inadequate fill containment with strips of filter fabric

FIGURE 60. Bulkhead damage, La Casa de los Caracoles, Belleair Beach

FIGURE 61. Two-unit building destroyed by Elena's waves

BELLEAIR SHORE, PINELLAS COUNTY

South of Belleair Beach is the Town of Belleair Shore with a shoreline length of 5,385 feet (1.02 miles). The Town consists of 58 separate Gulf front properties and three public beach accesses at 6th Street, 12th Street and 19th Street. The entire Town is bulkheaded, and as was the case at Belleair Beach, Belleair Shore sustained heavy damage from the wave impact and erosion of Elena.

Approximately 2,150 feet of concrete bulkheads were destroyed or substantially damaged by Elena and another 1,900 feet of wall sustained visible moderate to minor damage. This compares reasonably well with the damage reported by D. T. Tackney, P.E., for the Town. Tackney reported 2,080 feet of wall destroyed or damaged beyond repair, 1,080 feet of wall with repairable major damage, and 2,225 feet of wall with minor damage not in need of repair. This data was compiled by property lengths and therefore should not compare precisely to the figures cited in this report.

In addition to the extensive bulkhead damage by Elena, Belleair Shore had twelve major structures substantially damaged. Six single-family dwellings were destroyed or sustained substantial damage and three others sustained major structural damage. One swimming pool was destroyed and two others sustained major damage. Ironically, tropical storm Juan did not have the same impact to Belleair Shore that the communities to the south experienced. There was generally vertical accretion to the beach behind the remnant walls, thus reducing the quantity of backfill necessary in the reconstruction effort. D. T. Tackney, P.E., reported no additonal major structural damage due to Juan.

North of 18th Street a 150 foot segment of wall was completely destroyed and two residences were damaged (Figure 62). Between 18th Street and 17th Street the seaward end of a large residence was destroyed (Figure 63). South of 18th Street, with the exception of a damaged 100 foot segment still standing, a 650 foot stretch of wall was destroyed (Figure 64). With the lowering of the profile seaward of the walls and the loss of material from behind the walls, the structures could not withstand the direct wave impact loads. South of 16th Street a swimming pool structure also was destroyed by direct wave impact loads (Figure 65). A 160 foot segment of wall was completely destroyed south of 15th Street and another 160 foot segment was destroyed south of the 12th Street beach access (Figure 66). An 80 foot wall and seaward portion of a house was substantially destroyed adjacent to the Belleair Causeway and a 140 foot segment of wall was destroyed/damaged, a pool damaged, and the seaward portion of a house destroyed between the Belleair Causeway and 9th Street (Figure 67).

Adjacent 9th Street, two residences sustained heavy damage from undermining (Figure 68). A 400 foot length of bulkhead fronting these two residences and continuing south to 8th Street was destroyed along with another residence (Figure 69). Between 7th Street and the 6th Street beach access a 120 foot segment of wall was destroyed and a pool and residence damaged. A 40 foot section of wall was destroyed at 5th Street and a 160 foot segment was destroyed north of 3rd Street. Adjacent 2nd Street an 80 foot wall segment was destroyed and the seaward portion of a residence destroyed. The south end of the Town's walls sustained substantial cap damage.

FIGURE 62. North Belleair Shore damage

FIGURE 63. Belleair Shore dwelling damaged

FIGURE 64. Concrete bulkhead destroyed, 650 feet

FIGURE 65. Wall and pool destroyed

FIGURE 66. Beach, wall, and property destroyed

FIGURE 67. Wall destroyed and dwelling damaged

FIGURE 68. Wall destroyed and dwellings damaged

FIGURE 69. Wall and dwelling destroyed

INDIAN ROCKS BEACH, PINELLAS COUNTY

The greatest damage sustained by any Florida coastal community during the 1985 hurricane season was that sustained by the City of Indian Rocks Beach. Located south of Belleair Shore on northern Sand Key, Indian Rocks Beach has a shoreline length of 14,055 feet (2.66 miles). Most of Indian Rocks Beach had either concrete bulkheads, wooden bulkheads, or lesser strength retaining walls, and very little beach existed prior to the storms to buffer the wave activity.

Approximately 6,640 feet of wall was either destroyed or sustained major damage from Elena while an additional 1,065 feet of wall was destroyed or sustained major damage from Juan. Elena destroyed or substantially damaged 42 major structures and Juan destroyed or substantially damaged eight major structures in Indian Rocks Beach. The need for a wave energy absorbing sandy beach is extremely critical in Indian Rocks Beach. While several other communities have the same critical need, none are in any greater threatening situation than exists in this community.

The northernmost 950 feet of the City had a wood bulkhead which was destroyed by Elena. At 25th Avenue a 100 foot segment of concrete bulkhead was destroyed by Elena and a residence and pool were undermined (Figure 70). An additional fifteen feet of wall was destroyed by Juan. South of 24th Avenue a 100 foot segment of wall was destroyed by Elena and the seaward portion of a residence was substantially damaged (Figure 72). The owners neglected to take any emergency measures after Elena, and Juan completely destroyed the house (Figures 71 and 73).

At 23rd Avenue, 80 feet of concrete bulkhead was destroyed by Elena (Figure 74). The City took emergency measures to protect the streetend (Figure 75) but Juan caused an even greater erosion impact (Figure 76). At 22nd Avenue 100 feet of concrete bulkhead was destroyed, another 60 feet damaged, and the southwest corner of the Holiday Isles Motel was undermined (Figure 77). The property owner took emergency measures with sand bags to protect the motel from further undermining but Juan destroyed a 20 foot concrete return wall. To the south a 70 foot wood bulkhead was destroyed by Elena and the upland dwelling was threatened by Juan. The next 230 feet of concrete bulkhead through 21st Avenue sustained cap damage. South of 21st Avenue, 50 feet of wood bulkhead was destroyed and a residence was undermined by Elena. The property owner constructed a concrete block retaining wall beneath the dwelling's slab foundation and protected it from damage by Juan.

Extending north and south of 20th Avenue a 220 foot segment of concrete bulkhead was destroyed by Elena. A noncompatible black

dirt was used as fill behind the destroyed wall after Elena; however, Juan removed the fill, destroyed an additional 30 feet of wall and undermined and damaged an upland dwelling. North of 19th Avenue, 70 feet of concrete bulkhead was damaged by Elena. Of this segment, 30 feet of wall was completely destroyed by Juan and substantial erosion extended over 50 feet into the streetend from the wall. Immediately south of 19th Avenue, 100 feet of concrete bulkhead was destroyed by Elena and 50 feet of property eroded, representing nearly 750 cubic yards of property lost behind the wall. Juan eroded another 200 cubic yards from this property.

To the north of 18th Avenue, 100 feet of concrete bulkhead and two single-family dwelling structures were destroyed by Elena (Figures 78 and 80). Juan destroyed an additional 30 feet of street-end wall and caused additional damage to the already destroyed houses (Figure 79). Juan destroyed an additional 20 feet of wall at the property south of 18th Avenue.

At 17th Avenue, 130 feet of concrete bulkhead and two concrete block single-family dwellings were destroyed by Elena (Figure 81). Juan caused additional erosion south of 17th Avenue threatening the second row of dwellings 70 feet inland from the bulkhead. Approximately 1,430 cubic yards of barrier dune sediments were eroded at this site by both storms. In Post-Storm Report No. 85-2, Balsillie reported a net change of 16.74 cubic yards per foot of shoreline lost at this site.

An even greater loss occurred at the property south of 16th Avenue where over 200 feet of wall and two wood frame dwellings were destroyed and over 2,200 cubic yards of upland property was eroded by Elena (Figures 82 and 83). The dwellings would not have been destroyed had they been constructed on adequate pile foundations. Between the two collapsed wood frame dwellings was a small dwelling structure which cantilevered about 15 feet beyond the erosion escarpment. No effort was made to provide temporary supports or protection for this structure after Elena and it was destroyed by Juan. The wave activity of Juan also destroyed 50 feet of concrete bulkhead at the streetend but brought in probably 800 cubic yards of sand to this critically eroded site.

A red brick, slab-on-grade house located 200 feet south of 16th Avenue was undermined but survived Elena. The owner pumped in 40 cubic yards of concrete beneath his slab, constructed aluminum return walls, backfilled his damaged concrete bulhead with sand fill and an additional unspecified quantity of concrete, and sustained no damaged from Juan. To his south, the next five dwellings were either destroyed or sustained substantial damage from Elena (Figures 84 and 85). Additionally, 450 feet of concrete bulkhead through 15th Avenue was destroyed. One wood

frame dwelling located 150 feet north of 15th Avenue was sustantially damaged by Elena (Figure 86) and destroyed by Juan (Figure 87).

For the next approximately 730 feet to 12th Avenue, only cap, tieback, or other minor damages were sustained by the bulkheads during Elena; however, Juan destroyed a 70 foot segment and substantially damaged a 180 foot segment and a 50 foot segment. In addition, Juan substantially damaged two swimming pools beyond repair. Between 13th Avenue and 12th Avenue was the Big Indian Rocks Fishing Pier which was completely destroyed by Elena (Figure 88). The pier was nearly 1,500 feet in length and the debris from the pier was transported by the storm waves northward and deposited along the five mile stretch of shoreline to Clearwater Pass. Piling from the pier were frequently found in the backyards of Belleair Shore residents and were blamed as battering rams for some of their damage.

At 12th Avenue south of the pier, 60 feet of concrete bulkhead was destroyed by Elena. The wall between 12th Avenue and 11th Avenue sustained no major damage from Elena but 300 feet of wall sustained major damage from Juan. To the south at the Reef Club, 100 feet of wall was destroyed or substantially damaged by Elena. From 10th Avenue south, 300 feet of continuous concrete bulkhead was destroyed by Elena. Additionally, one single-family dwelling structure was destroyed and two others were damaged from undermining. At the Reflections a clubhouse or recreational structure was destroyed along with 75 feet of concrete bulkhead. The remaining 350 feet of wall at the Reflections through 9th Avenue sustained minor damage.

Between 9th Avenue and 8th Avenue, 450 feet of wood and concrete bulkheads were destroyed, three single family dwellings were destroyed, and six other dwellings sustained major damage from Elena (Figures 89 and 90). South of and including 8th Avenue most of the 860 feet of wall to 7th Avenue was destroyed or sustained major damage from Elena (Figure 91). The six single-family dwellings south of 8th Avenue were either destroyed or substantially damaged by Elena (Figure 92). Additional damage was sustained by Juan (Figure 93).

At 7th Avenue, the City replaced fill along Beach Drive for access after Elena (Figure 94). Juan removed the backfill that had been placed (Figure 95). Approximately 400 feet south of 7th Avenue and continuing southward past 6th Avenue for 680 feet, the old Beach Drive concrete wall was destroyed or substantially damaged by Elena. Most of all of the Beach Drive road fill was lost and a couple dwellings were undermined. The 250 foot pier south of 5th Avenue which previously lost 50 feet to an earlier storm (probably the subtropical storm of June 18, 1982) surprisingly had no visible signs of major damage after Elena or

Juan. Minimal damage was evident between 5th Avenue and 2nd Avenue after either storm as a narrow beach existed.

North of 2nd Avenue, a 50 foot bulkhead was destroyed by Elena along with a single-family dwelling (Figure 96). To the south of 2nd Avenue, 110 feet of concrete bulkhead was destroyed by Elena and a single-family dwelling was substantially damaged by Juan. South of 1st Avenue, a 60 foot concrete bulkhead and a single-family dwelling were destroyed by Elena. Another 50 foot segment of concrete bulkhead was damaged by Elena 200 feet south of 1st Avenue.

Sand Key becomes very narrow at a central location six miles south of its north tip at Clearwater Pass. This central stretch of the island is adjacent a narrow barrier lagoon called the Narrows and averages 250 feet in width along a half mile length. It is thought that this area with its north/south shoreline alignment is a nodal point of longshore sediment transport. To the north, a predominantly northward net transport occurs while to the south a net southward longshore transport exists. This island stretch along the Narrows defines the south limits of Indian Rocks Beach and the Town of Indian Shores.

Immediately north of the beach access at Central Avenue, 300 feet of concrete bulkhead was destroyed at the Happy Fiddler Condominium (Figure 97). Some of the damaged wall which was still standing after Elena was leveled by the storm waves of Juan (Figure 98). To the south of Central Avenue, the 50 Gulfside Condominium sustained no major damage from Elena. After the June 18, 1982 subtropical storm destroyed the south 100 feet of wall, a relocated wall with rock toe-scour protection was authorized and constructed. To replace the concrete deck lost in the landward relocation of the wall, a pile supported wood deck was authorized and constructed although the expendable wood decking was lost. The toe scour protection worked as designed to minimize erosion and protect the wall during Elena (Figure 99). The structure continued to perform as designed during Juan (Figure 100).

South of the 50 Gulfside Condominium 300 feet of concrete wall between the Beachcomber and the Sunset View Motel and 150 feet of a new wood fishing pier was destroyed by Elena. Juan destroyed another 100 feet of the pier. At the south limits of Indian Rocks Beach, 80 feet of concrete bulkhead was destroyed and an apartment building and 220 feet of wall was substantially damaged by Elena (Figure 101). Juan additionally damaged the building and completely destroyed the 220 feet of concrete wall (Figure 102).

FIGURE 70. Damage at 25th Avenue, Indian Rocks Beach

FIGURE 71. Dwelling destroyed by Juan

FIGURE 72. Dwelling damaged by Elena

FIGURE 73. Same dwelling destroyed by Juan

FIGURE 74. Elena damaged 23rd Avenue

FIGURE 75. Post-Elena emergency protection, 23rd Avenue

FIGURE 76. Juan destroyed 23rd Avenue

FIGURE 77. Elena destroyed 22nd Avenue

FIGURE 78. Elena destroyed 18th Avenue dwellings

FIGURE 79. Juan's additional damage at 18th Avenue

FIGURE 80. Wall and dwellings destroyed by Elena

FIGURE 81. Dwellings destroyed at 17th Avenue

FIGURE 82. Wall, dwellings and property destroyed, 16th Avenue

FIGURE 83. Frame dwelling collapsed when undermined

FIGURE 84. Bulkhead and dwellings damaged

FIGURE 85. Dwelling damaged by Elena

FIGURE 86. Dwelling damaged by Elena

FIGURE 87. Same dwelling damaged by Juan

FIGURE 88. Big Indian Rocks Fishing Pier destroyed

FIGURE 89. Bulkheads and dwellings destroyed and damaged

FIGURE 90. Dwelling destroyed by Elena

FIGURE 91. Bulkheads and dwellings destroyed and damaged

FIGURE 92. Elena destroyed 8th Avenue

FIGURE 93. Dwelling damage by Juan

FIGURE 94. Post-Elena fill at 7th Avenue

FIGURE 95. Juan eroded street-end fill, 7th Avenue

FIGURE 96. Dwelling destroyed by Elena, 2nd Avenue

FIGURE 97. Happy Fiddler Condominium bulkhead after Elena

FIGURE 98. Happy Fiddler Condominium bulkhead after Juan

FIGURE 99. Toe-scour protection after Elena, 50 Gulfside Condominium

FIGURE 100. Toe-scour protection after Juan

FIGURE 101. South Indian Rocks Beach after Elena

FIGURE 102. South Indian Rocks Beach after Juan

INDIAN SHORES, PINELLAS COUNTY

Along the middle of Sand Key extending southward along the Narrows for a length of 13,500 feet (2.56 miles), the Town of Indian Shores experienced substantial damage from Elena, but very little additional damage from Juan. While most of Indian Shores is bulkheaded, significant stretches are not armored and have narrow beaches. Elena destroyed or substantially damaged 3,200 feet of wall and Juan destroyed an additional 65 feet of wall. An estimated 2,500 feet of wall also received minor damage from Elena. In addition to the wall damage, Elena destroyed or substantially damaged 30 major structures, and Juan destroyed one more. As is the case at Indian Rocks Beach, Indian Shores is in critical need of beach restoration.

As reported in Post-Storm Report No. 85-2, the Bureau of Coastal Data Acquisition measured substantial erosion along Indian Shores. Although there was no profile data immediately prior to the storm from which to compare the profiles obtained two weeks after Elena, most of the erosion measured is thought to have been attributable to this storm. It is interesting to note that Juan caused more accretion through Indian Shores and therefore was substantially less damaging than Elena. The beach berm was observed to have accreted vertically by one to three feet throughout most of the area, except where no beach remained after Elena and wave activity continued to scour the profile seaward of vertical walls.

At the north limits of Indian Shores a single-family dwelling was destroyed by Elena (Figure 103). After Juan, three feet of vertical accretion of the profile was observed (Figure 104). In the Narrows area at the north end of Indian Shores, 520 feet of concrete and wood bulkheads were destroyed or substantially damaged by Elena.

In the area of the Sand Castle Condominiums little damage was observed. Much of the beach lost to Elena returned during Juan. In the block to the south, three single-family dwellings were undermined and threatened by Elena. The beach was approximately 50 feet wide after the storms at 199th Avenue. South of 199th Avenue, 265 feet of wall and a single-family dwelling were destroyed and three townhouse structures and a single-family dwelling were undermined and threatened from any further erosion. Between 198th Avenue and 197th Avenue, seven single-family dwellings were destroyed or substantially damaged and the other dwellings were undermined and threatened from further erosion (Figure 105). A 160 foot wood bulkhead was destroyed by Elena and another 15 foot segment was destroyed by Juan. Three of the damaged dwellings were behind a 115 foot segment of concrete wall which was destroyed by Elena (Figures 106 and 107). South of

197th Avenue a 100 foot wood bulkhead and a single-family dwelling were also destroyed by Elena.

From 196th Avenue to the south, 400 feet of wood bulkhead was destroyed. Further south another 100 foot bulkhead segment was destroyed. To the north of the Indian Shores Town Hall, 820 feet of concrete and wood bulkheads were destroyed or substantially damaged (Figures 108 and 109). This area also had a swimming pool destroyed at the Sea Gate Condominium and a single-family dwelling and motel unit were damaged. Over 3,000 cubic yards of barrier dune sediment was eroded from behind this stretch of bulkhead.

The recent changes of the area may be seen at 193rd Avenue where the gently sloping beach after the subtropical storm in June 1982 (Figure 111) was replaced with the armored shoreline shown after Elena in September 1985 (Figure 112). Upland erosion was reduced, but at the expense of any beach. This wall was damaged by Juan.

To the south of 193rd Avenue, the concrete bulkhead at the Point Condomnium is inappropriately sited seaward of all adjoining structures. The massive wall is one of few in the area designed for compressive loads with concrete encased tiebacks. The wall only sustained minor damage, the south return wall was destroyed, and the understructure area to the building was gutted by wave wash. To the south of the Point, 100 feet of concrete bulkhead was destroyed or substantially damaged at the Rose Condominium. South of the Rose, 225 feet of wall fronting the Shangrala and the Sun and Surf properties was destroyed.

About 100 feet south of the Sun and Surf, 150 feet of inappropriately designed and sited wood bulkhead was destroyed by Elena. After the storm the property owners appeared more preoccupied with criticizing the minimum construction standards of the Department of Natural Resources and sustained additional erosion and structural damage due to Juan. A new concrete bulkhead was being constructed across the vacant southernmost 50 feet north of the Edgewater Motel but the structure was completely destroyed by Juan. At the Edgewater Motel, 110 feet of concrete bulkhead was destroyed by Elena and some of the replacement wall was destroyed by Juan (Figure 110). Toe scour protection is critically needed in front of these walls if they are to survive any significant storm conditions. In view of the failures of vertical walls at these properties, it is amazing that the property owners have not abandoned the costly and less durable walls for a more protective massive rock mound structure.

South of 190th Avenue, 100 feet of concrete bulkhead and 100 feet of wood bulkhead was destroyed by Elena (Figure 113). The concrete bulkhead was completely leveled and the swimming pool

destroyed by Juan. There was no major wall damage between 189th Avenue and 186th Avenue. At the Gulf Shores Condominium which characterizes the worst of coastal planning and development in Florida, no beach remains after the storms. An inappropriately designed cantilevered concrete deck was destroyed by the uplift forces of Elena's storm waves (Figure 114).

South of the Gulf Shores, a 40 foot wide low tide beach exists. North of 186th Avenue a large house was destroyed and to the south a 130 foot wood bulkhead was destroyed by Elena. The southernmost of two private fishing piers located at the south limits of Indian Shores was substantially destroyed by Elena. Juan provided substantial sand accretion throughout this area between the Gulf Shores in Indian Shores and the Shore Mariner in Redington Shores.

FIGURE 103. Indian Shores dwelling destroyed by Elena

FIGURE 104. Same dwelling with beach accreted by Juan

FIGURE 105. Dwelling destroyed by Elena

FIGURE 106. Wall damaged by wave impact loads

FIGURE 107. Wall destroyed and dwellings damaged

FIGURE 108. Indian Shores bulkheads destroyed, 820 feet

FIGURE 109. Indian Shores bulkheads destroyed, 820 feet

FIGURE 110. New bulkhead damaged without toe-scour protection

FIGURE 111. 193rd Avenue after the No Name Storm, 1982

FIGURE 112. No beach at 193rd Avenue after Elena

FIGURE 113. Bulkhead destroyed by Elena

FIGURE 114. Gulf Shores Condominium after Elena

REDINGTON SHORES, PINELLAS COUNTY

South of the Narrows adjacent the north end of Boca Ciega Bay is the Town of Redington Shores with a shoreline length of 6,200 feet (1.17 miles). Most of Redington Shores is bulkheaded; however, most of the damage from both Elena and Juan was limited to the area of erosion stress between the Suncoast Seabird Sanctuary and the Pinellas County Park. This area of beach was substantially eroded by the subtropical storm of June 18, 1982 (commonly referred to as the "No Name Storm").

At the Shore Mariner Condominium, Elena destroyed 150 feet of concrete bulkhead and a large swimming pool (Figure 115). Additional segments of the wall, although standing, were damaged. An additional segment of wall was destroyed by Juan; however, the property owners had taken emergency measures with temporary revetment construction and prevented any building damage (Figure 116). South of the Shore Mariner a 70 foot segment of concrete wall was destroyed by Elena.

Approximately 220 feet of concrete wall was destroyed by the "No Name Storm" in 1982 north of and including the northwest corner of the wall at the county park. A new 350 foot long concrete bulkhead was constructed at the park 50 feet landward of the old wall and in alignment with the coastal construction control line. Two new concrete bulkheads were also constructed along the control line fronting three separate properties extending 300 feet north of the park. Tangential to and offshore from the county park is the site of the first offshore breakwater on the outer coast of Florida. The site was also proposed for beach nourishment; however, all the planning and implementation had not proceeded soon enough to spare this area from further damage by Elena and Juan. An 80 foot wall and a 60 foot wall, not previously destroyed in the "No Name Storm", were destroyed by Elena and the two single-family dwellings adjacent to the park were undermined and damaged.

During Halloween Eve this area was substantially impacted by the storm waves of Juan. Two dwellings were damaged from underming and one dwelling suffered substantial damage from wave loading and undermining (Figure 117). At another residence 150 feet north of the park, a 60 foot aluminum wall constructed for emergency protection was destroyed (Figure 118). An emergency sand bag structure, constructed through the night, prevented the loss or substantial damage to this threatened residence. Elena had destroyed the original wall and eroded 25 feet into the property and Juan eroded another 20 feet up to the front of the house before any further erosion could be prevented.

Further to the south in Redington Shores, two concrete block, grade level dwellings sustained damage from waves which

overtopped a low concrete bulkhead which extends further seaward than any adjoining walls.

In summary, 370 feet of wall was destroyed or substantially damaged and 1,250 feet of wall sustained minor damage from Elena in Redington Shores. In addition, Elena destroyed a pool and damaged four dwellings. Juan destroyed 150 feet of wall and damaged three dwellings.

FIGURE 115. Wall and pool destroyed, Shore Mariner Condominium

FIGURE 116. Emergency revetment protection from Juan

FIGURE 117. Redington Shores dwelling damaged by Juan

FIGURE 118. Emergency protection after Juan

NORTH REDINGTON BEACH, REDINGTON BEACH, AND MADEIRA BEACH, PINELLAS COUNTY

On southern Sand Key between Redington Shores and Redington Beach is the Town of North Redington Beach with a shoreline length of 4,300 feet (0.81 mile). Most of North Redington Beach is bulkheaded. The north 700 feet has a narrow beach remaining and the south 2,000 feet has a fairly wide beach for the area due in part to less encroachment into the active beach system with bulkheads and other development. The other 1,600 feet of shoreline has no beach and is in critical need of both nourishment and revetment construction. Within this area of erosion stress 500 feet of concrete wall was destroyed and three major structures were damaged by Elena. An additional 120 feet of wall was destroyed, a pool was destroyed, and two buildings sustained major damage by Juan. The rest of the nearly 1,000 feet of wall sustained minor damage from the storms.

At a vacant property south of the Ramsea property, 1,000 feet of concrete bulkhead was destroyed. Additional wall left standing by Elena was knocked down by the storm waves of Juan. To the south, 120 feet of wall at the Sandlewood, which previously only sustained minor damage from Elena, sustained heavy damage from Juan. The Sandlewood sustained heavy wave damage to its foundation and lower floor structures. Adjacent to the Sandlewood, the Flagship property sustained heavy wave damage from both storms. A 130 foot segment of wall was destroyed by Elena (Figure 119). The Flagship property received a substantial battering by the storm waves of Juan which destroyed the pool and leveled any standing wall panels (Figure 120). A 70 foot segment of wall at the Islander was destroyed by Elena. In addition the seaward unit of the north building was destroyed by Elena's wave activity (Figure 121). This property was also battered by Juan as additional wave damage was inflicted on the building (Figure 122). Further to the south between the Islander and the Redington Ambassador another 120 feet of bulkhead was destroyed by Elena and additionally leveled by Juan. Most of the remaining bulkheads sustained lesser damage. At the Bath Club property a dwelling and cabana building were undermined and damaged by Elena.

South of North Redington Beach, the Town of Redington Beach has a shoreline length of 5,550 feet (1.05 miles). No major damage was sustained by either Elena or Juan in Redington Beach; however, 700 feet of bulkhead sustained minor damage by Elena. Minor beach erosion was observed along Redington Beach after Elena and additional beach erosion was observed after Juan. No beach profiles were obtained in this area after the storms.

At the southern end of Sand Key, the City of Madeira Beach with a shoreline length of 1,860 feet (2.06 miles), sustained no major

damages. Substantial beach profile lowering occurred north of the Holiday Inn during Elena, but Juan brought in sand to vertically accrete the beach berm by two to three feet. Elena's storm waves overtopped the Holiday Inn bulkheads and caused erosion and damage to the deck area behind the wall. Juan substantially eroded the beach profile adjacent to the Holiday Inn but did no additional structural damage to the upland property. Only minor beach erosion conditions were observed along the remainder of Madeira Beach and the area is expected to rapidly recover as the beach returns to its normal profile.

FIGURE 119. Flagship property damage after Elena

FIGURE 120. Additional damage and pool destroyed by Juan

FIGURE 121. The Islander after Elena's damage

FIGURE 122. The Islander after Juan's additional damage

TREASURE ISLAND, LONG KEY, MULLET KEY, AND EGMONT KEY, PINELLAS AND HILLSBOROUGH COUNTIES

Although the fourteen mile long Sand Key sustained substantial structural damages, the other islands of Pinellas County while not sustaining major structural damages, did experience substantial beach erosion. South of Sand Key, Treasure Island with a shoreline length of three and one-half miles sustained heavy beach erosion from both Elena and Juan.

Based upon surveys obtained by the U. S. Army Corps of Engineers, Jacksonville District, an estimated 550,000 cubic yards of sand was eroded from the beach of Treasure Island by Elena. Because Treasure Island was a federally authorized beach restoration project it qualified for emergency maintenance nourishment with this quantity of material. No surveys were conducted after Juan; however, the north and south ends of the island reflected substantial erosion due to Juan. Immediately south of Johns Pass on the north end of Treasure Island 65,000 cubic yards of sand was being stockpiled from the maintenance dredging of Johns Pass. This stockpiled material was to be used in the nourishment project at Redington Shores. Only 35,000 cubic yards of sand remained for the Redington Shores project after Juan representing a cumulative loss of 30,000 cubic yards from both storms. A comparison of the current shoreline position with the Department's 1974 aerial photography reflects approximately 800 feet of shoreline recession in this area. In this area, between 121st Avenue and 120th Avenue new low-rise beach front condominiums under construction sustained roofing damages from Elena's winds while this area was substantially flooded.

Paralleling Blind Pass, the south end of Treasure Island is called Sunset Beach. This area was subject to heavy erosion from both Elena and Juan. Elena substantially overtopped the beach area and pushed in sand along West Gulf Boulevard south of the intersection with Bay Shore Drive. To the north of this intersection, the Sunset Chateau Condominium sustained 390 feet of bulkhead cap damage from Juan (Figure 123). South of 81st Avenue, the dune restoration project provided adequate protection from inland flooding.

South of Treasure Island, between Blind Pass and Pass-a-Grille lies Long Key with a Gulf Beach length of over four miles. St. Petersburg Beach on Long Key is, like Treasure Island, a federally authorized beach restoration project. Prior to Elena this beach had already been authorized for maintenance nourishment with 226,000 cubic yards of sand along the north end and had been authorized and contracted for 20,000 cubic yards of nourishment along the south end.

The federal project at the north end of Long Key includes an offshore rock mound breakwater. This area which is located immediately south and down drift of Blind Pass is subject to critical erosion and wave energy stress. Some damage was sustained to concrete decks by Elena, but most of the damage in this area was sustained by Juan. At the Envoy Point Condominium immediately south of the Blind Pass south jetty 450 feet of concrete bulkhead and rock revetment but was destroyed by the impact of waves overtopping the wall. South of Envoy Point at the Starlight Tower Condominium 230 feet of bulkhead cap damage was sustained. The bulkhead was overtopped and substantial fill was lost resulting in the swimming pool being floated out of the ground and being damaged beyond repair (Figure 124). South of the Starlight Tower at the construction site of the new Caprice Condominium, Juan damaged 100 feet of bulkhead cap and destroyed 40 feet of return wall.

Heavy beach and dune erosion was sustained by Elena and Juan south of the Caprice along the public beach. Unfortunately the post-storm profile obtained after Elena at this location by the survey team of the Bureau of Coastal Data Acquisition cannot be compared with a prestorm profile. Although post-storm report No. 85-2 reflects a 22 foot retreat in the shoreline, the comparison was made with a 1974 profile taken before the beach restoration project and therefore the recession caused by Elena was most probably even greater. It can at least be said that the beach conditions are worse now than they were prior to the initial beach nourishment project for this area.

The profiles obtained along the south end of Long Key and reported in Post-Storm Report No. 85-2 reflect the recent beach nourishment in this area and are not representative of the erosion or accretion caused by Elena. For example the profile obtained at the Department's reference monument R-153 does not reflect the severe erosion witnessed in this area but shows 64 feet of accretion when compared with a profile obtained in 1974. Given the eleven year period between the two sets of profiles, none of the Pinellas County erosion data should be considered as the result of Elena. The subtropical storm of 1982 caused substantial erosion in Pinellas County and a comparison of the post-Elena profiles with those obtained after the No Name Storm would be substantially more indicative of the impact of Elena. Unfortunately, there has been no post-Juan survey to compare with the post-Elena survey. At the south end of Long Key along Gulf Way, 3,000 feet of concrete block wall constructed as a sand barrier was destroyed by Juan.

Had profiles been obtained along Mullet Key, a few miles south of Long Key, accretion would have been noticed not due to Elena but due to beach nourishment and the emergence of a new coastal barrier at the island's north end. An inlet broke through during

Elena and a 148 foot long three-masted schooner was grounded on this new coastal barrier. The owners of the ship had hoped to remove the vessel during the high water associated with Juan but the attempt resulted in one of the owners drowning. Ft. DeSoto Park on Mullet Key sustained no major damages but did receive substantial flooding and sand which was transported onto parking areas by both Elena and Juan.

Across Egmont Channel from Mullet Key at the entrance to Tampa Bay lies Egmont Key which is federally owned and maintained. Heavy beach and dune erosion was observed along the entire Gulf front of the island after Elena. No observations were made after Juan.

FIGURE 123. Juan damaged Sunset Chateau Condominium's bulkhead, Treasure Island

FIGURE 124. Pool at Starlight Tower Condominium floated above grade during Juan's flooding, St. Petersburg Beach

ANNA MARIA ISLAND, MANATEE COUNTY

South of Tampa Bay lies the coastal barrier of Anna Maria Island with a shoreline length of about seven and one-half miles. Similar to Sand Key north of Tampa Bay, Anna Maria Island experienced its moderate to heavy beach erosion along the central portion with less erosion and damage at the north and south ends during Elena and Juan.

Although further away from the center of Elena than Sand Key, Anna Maria Island experienced significant though substantially less damage than Sand Key. On a weighted shoreline comparison, Anna Maria Island's structural damage to rigid coastal protection structures was roughly twenty percent or one-fifth of that sustained on Sand Key. A combination of wider beach and the use of energy dissipating revetments and rock mounds where little beach existed, appeared to be two reasons for the lower damage sustained on Anna Maria Island. However, during Juan, on a weighted shoreline comparison, Anna Maria Island sustained roughly ninety percent of the bulkhead damage sustained on Sand Key. In other words, during Juan the bulkhead damage was equally severe on Anna Maria Island as on Sand Key. During both Elena and Juan, Anna Maria Island sustained rougly twenty-five percent or one-fourth of the damage to major structures as did Sand Key.

No major damage was sustained on the north two and one-half miles of Anna Maria Island which includes the City of Anna Maria and the north three-quarter mile of the City of Holmes Beach. Generally only minor beach erosion was observed in this area due to Elena and Juan.

Immediately south of the end of 67th Street in Holmes Beach, a 70 foot concrete wall was damaged by Juan. At the Waters Edge Condominium major wave damage was sustained to the lower floor area of the building during Elena (Figure 125). South of the Waters Edge a 50 foot concrete wall was destroyed by Juan and a 150 foot concrete bulkhead was destroyed by Elena. South of 56th Street a single-family dwelling was undermined and sustained wave damage by Elena and its deck roof collapsed. To its south, the Sun Plaza West Condominium sustained damage to the understructure area.

At the Martinique North Condominium 175 feet of sloping concrete wall was destroyed by Juan (Figure 126). The Martinique North Condominium also sustained major wave damage to the building's lower floor. At the 5400 Condominium to the north, 400 feet of wall sustained minor damage but will need to be replaced. Substantial erosion losses were sustained from behind all the walls in this area during both Elena and Juan. At 52nd Street a 40 foot concrete return wall was destroyed or substantially

damaged by Elena and about 250 cubic yards of sand was eroded from the street-end by each storm event. Between 52nd Street and 48th Street, 720 feet of concrete bulkhead was destroyed by Elena and another 200 feet of bulkhead was destroyed by Juan (Figure 127). Minor damage was sustained by 40 feet of bulkhead at 48th Street. Between 49th Street and 50th Street, a concrete block, slab-on-grade, single-family dwelling sustained heavy erosion and wave damage from Elena (Figure 128). As was often the case in Pinellas County, Juan brought in much of the sand lost during Elena as shown by the accretion on the same damaged dwelling after Juan (Figure 129).

At the Manatee County Park between 42nd Street and 40th Street the beach is between 100 to 150 feet wide. The wide beach exists substantially because of the sand trapping capacity of the concrete pier of low deck elevation and subsurface concrete groin panels. This pier-groin sustained heavy damage to a 100 foot section during Juan (Figure 130).

Between 37th Street and 36th Street, 250 feet of rock mound or revetment was substantially damaged by Elena. Although this was an authorized structure, the project was not constructed as designed nor was final certification of project completion accepted. South of 36th Street a 60 foot concrete bulkhead was destroyed and a single-family dwelling was undermined and damaged by Juan. South of 34th Street a 100 foot revetment was damaged and a single-family dwelling was undermined by Elena. South of the property, 150 feet of concrete bulkhead with toe-scour protection and two single-family dwellings were destroyed by Elena (Figures 131 and 132). To the south another single-family dwelling was undermined and damaged and had to be lifted and placed on temporary supports (Figure 133). The adjacent property lost its 50 foot concrete bulkhead to Elena.

South of 32nd Street, 90 feet of concrete bulkhead with toe-scour protection was destroyed by Elena (Figure 134) and one single-family dwelling was substantially destroyed by erosion and waves (Figure 135). Adjacent 31st Street, 40 feet of concrete bulkhead was destoyed by Juan. Near the south end of Holmes Beach 50 feet of concrete bulkhead was destroyed by Juan. South of 28th Street, a concrete deck at a single-family dwelling was destroyed by both Elena and Juan. A 40 foot concrete block wall built in violation after Elena was destroyed by Juan.

At the north city limits of the City of Bradenton Beach, the Anna Maria Island Club Condominium sustained substantial damage to its pool deck, understructure parking decks, breakaway walls, and associated expendable minor structures by both Elena and Juan. South of 25th Street, at the Sand and Sea Motor Hotel a single-family dwelling was damaged by Elena and subsequently removed.

Between 23rd Street and 22nd Street is currently the area of most critical erosion in Bradenton Beach. South of 23rd Street a 40 foot section of concrete bulkhead was destroyed by Juan. At a Department of Natural Resources reference monument number R-28, an erosion loss between April 26, 1985 and October 10, 1985 was calculated to be approximately seventeen and one-half cubic yards per foot of shoreline as reported in Post-Storm Report No. 85-2. A single-family dwelling adjacent to this profile was undermined and damaged by Elena (Figure 137) and destroyed by Juan (Figure 138). The adjacent dwelling was destroyed by Elena (Figure 136) and 150 feet of concrete bulkhead was destroyed along this stretch (Figure 139). Another dwelling to the south sustained major damage and foundation settlement by Elena and Juan (Figure 140). El Bandito Motel sustained damage to the building by Elena and 100 feet of the road pavement at Gulf Drive was damaged. Subsequent to Juan an emergency rock revetment was constructed to protect the road. With the exception of three pier-groins being damaged by Elena no other major damage was sustained along Bradenton Beach or the south two and one-half miles of Anna Maria Island.

FIGURE 125. Waters Edge Condominium damaged by Elena (S. West)

FIGURE 126. Juan destroyed sloping wall at Martinique Condominium

FIGURE 127. Elena and Juan destroyed 920 feet of bulkhead

FIGURE 128. Dwelling damaged by Elena

FIGURE 129. Juan's beach accretion at damaged dwelling

FIGURE 130. Juan damaged pier-groin at County park

FIGURE 131. Holmes Beach dwelling destroyed by Elena (S. West)

FIGURE 132. Bulkhead destroyed by wave impact loads

FIGURE 133. Undermined dwelling on temporary supports

FIGURE 134. Bulkhead with toe-scour protection destroyed

FIGURE 135. Holmes Beach dwelling destroyed by Elena

FIGURE 136. Bradenton Beach dwelling destroyed by Elena

FIGURE 137. Bradenton Beach dwelling damaged by Elena (S. West)

FIGURE 138. Same dwelling destroyed by Juan

FIGURE 139. Bulkheads destroyed by wave loads

FIGURE 140. Dwelling damaged and settled

LONGBOAT KEY, MANATEE AND SARASOTA COUNTIES

South of Anna Maria Island and Longboat Pass lies the coastal barrier of Longboat Key which has a shoreline length of ten and a quarter miles. The north one mile and south three miles sustained no major damage from either Elena or Juan. Longboat Key experienced only a small fraction of the structural damages sustained by Anna Maria Island during Elena, but Juan delivered significantly more structural damages to Longboat Key, although they were spread along a greater shoreline length.

Approximately one mile south of Longboat Pass considerable structural damage occurred along Gulfside Drive. At one property, 100 feet of concrete bulkhead was destroyed, 40 feet by Elena and 60 feet by Juan, and the front deck and decorative wall seaward of the dwelling were destroyed by Juan. At the dwellings immediately to the south a patio and a deck and spa were destroyed by Juan. Further south, two single-family dwellings and a groin sustained major damage by Elena and Juan. One dwelling sustained wave damage to its lower floor (Figure 141). The other dwelling experienced roof collapse from the constant impact of Juan's storm waves (Figure 143). This dwelling was also substantially damaged from flanking wave attack around its south side (Figure 144).

Further south a continuous 700 foot stretch of concrete bulkhead was destroyed by Juan (Figure 142). Considerable erosion took place landward of the bulkhead resulting in a number of large Australian pine trees being toppled (Figures 145 and 146). Notwithstanding the two beach profile computations at DNR reference monument numbers 51 and 54 as reported in Post-Storm Report Number 85-2, moderate to heavy beach erosion took place along the two mile stretch south of this area of heavy structural damage. This area experienced wave overtopping and one swimming pool was damaged by Juan beyond repair.

Near the south end of Manatee County, a 100 foot concrete bulkhead was destroyed by Juan adjacent a dwelling south of the Casa del Mar Condominiums (Figure 147). The Longboat Harbor Towers lost 90 feet of concrete bulkhead during Elena and an additional 120 feet of wall and the swimming pool during Juan (Figure 148).

Near the north end of Sarasota County on the middle of Longboat Key, more structural damages were sustained by both storms. At the Seabird Condominium 150 feet of concrete bulkhead was destroyed by Juan. At the Seahorse Condominium 400 feet of concrete bulkhead was destroyed, 150 feet by Elena and 250 feet by Juan (Figure 149). South of the Seahorse, a 30 foot segment of concrete bulkhead was destroyed and south of Buttonview Drive

another 35 feet of concrete bulkhead was destroyed by Elena. In the vicinity of Neptune Avenue, 150 feet of concrete bulkhead was destroyed by Elena and another 60 feet was destroyed and 90 feet substantially damaged by Juan. A 75 foot wood bulkhead and a single-family dwelling was destroyed by Elena (Figure 150).

FIGURE 141. Subfloor damage to Longboat Key dwelling

FIGURE 142. Juan destroyed 700 feet of bulkheads

FIGURE 143. Longboat Key dwelling under wave attack (S. West)

FIGURE 144. Same dwelling destroyed by wave flanking (M. Joity)

FIGURE 145. Severe erosion on Longboat Key (S. West)

FIGURE 146. Australian pine toppled by erosion (S. West)

FIGURE 147. Juan destroyed concrete bulkhead

FIGURE 148. Juan destroyed pool and bulkhead, Longboat Harbor Towers (S. West)

FIGURE 149. Seahorse Condominium bulkhead destroyed by both storms (S. West)

FIGURE 150. Sarasota County dwelling destroyed by Elena (S. West)

SARASOTA COUNTY THROUGH COLLIER COUNTY

South of Longboat Key, the other barrier islands of Sarasota County sustained isolated damages from Elena and Juan. The most significant damage sustained were a few segments of island roads which were highly exposed to storm tides and wave uprush.

On Lido Key there were no major damages and only minor beach erosion from the storms. At the north end of Siesta Key, 300 feet of Beach Road was damaged (Figure 151). Elena caused minor to moderate beach erosion conditions and minor flooding along Siesta Key (Figure 152). At the south end of Point O' Rocks on Siesta Key, a 15 foot segment of concrete bulkhead was destroyed by Elena and an additional 100 feet of bulkhead cap was damaged. At a 200 foot length of property on Sanderling Road a quarter mile south of Point O' Rocks, 100 feet of concrete bulkhead was destroyed by Elena and 100 feet of wall was destroyed by Juan. No other major damage was observed on Siesta Key.

Along Casey Key, three segments of Casey Key Road totaling 2,500 feet were damaged by Elena. New road fill placed after Elena was eroded by Juan. In Venice, south of Rock Creek, 300 feet of concrete wall cap was damaged by Juan. A 100 foot length of concrete bulkhead located 400 feet south of Rock Creek was destroyed by Juan (Figure 153) and a 200 foot length of concrete bulkhead located 500 feet south of Rock Creek was destroyed by Elena (Figure 154). Further south along Manasota Key, a 150 foot wooden bulkhead was destroyed and 1,000 feet of the Manasota Key Road was destroyed by Elena.

The coastal barriers of Charlotte, Lee, and Collier Counties generally sustained only minor beach erosion from Elena and Juan. On Captiva Island in Lee County a single-family dwelling was destroyed and completely removed by the storm tide and waves of Juan. Further south on Sanibel Island, the seaward end of a two-unit motel structure at the Santiva Cottages was destroyed by the wave loads of Juan.

FIGURE 151. Beach Road damaged on Siesta Key (S. West)

FIGURE 152. Siesta Key flooding during Elena (S. West)

FIGURE 153. Juan destroyed Venice bulkhead (S. West)

FIGURE 154. Elena destroyed Venice bulkhead (S. West)

SUMMARY OF STRUCTURAL DAMAGES, HURRICANE ELENA

ESCAMBIA COUNTY

200 ft. concrete retaining walls destroyed
1 mi. Fort Pickens Road destroyed
1 motel sustained major damage to 27 units
1 Pensacola Beach Pier, 137 feet destroyed
1 Navarre Pier, 160 feet destroyed, 60 feet damaged
3 Major structures (excluding roads) destroyed or major damage

GULF COUNTY

1 fishing pier sustained major damage

FRANKLIN COUNTY

2,600 ft. bulkheads destroyed or sustained major damage
330 ft. rock revetment destroyed or sustained major damage
5,150 ft. paved road destroyed (Alligator Point and St. George Island)
20,650 ft. paved road sustained minor damage (St. George Island)
1,600 ft. causeway damaged (St. George Island)
? ft. U.S. 98 damaged (123,100 square feet of pavement destroyed)
58,000 cu.yds. fill lost from St. George Island causeway
130,000 cu.yds. fill lost from U.S. 98
21 single-family dwellings destroyed or sustained major damage
1 community recreation building destroyed
22 major structures (excluding roads and causeways) destroyed or sustained major damage

WAKULLA COUNTY

1 pier and pier house structure sustained major damage

LEVY COUNTY

115	ft. concrete bulkheads destroyed
240	ft. concrete bulkheads sustained major damage
1,000	ft. State Road 24 damaged
500	ft. First Street damaged
8	single-family dwellings sustained major damage
3	mobile homes destroyed
1	mobile home sustained major damage
2	motel buildings sustained major damage
1	restaurant sustained major damage
2	fishing piers destroyed
17	major structures destroyed or sustained major damage

PINELLAS COUNTY

16,110	ft. (3.05 mi.) bulkheads destroyed or sustained major damage
14,375	ft. (2.72 mi.) bulkheads sustained minor damage
43	single-family dwellings destroyed
32	single-family dwellings sustained major damage
3	condominium units destroyed
3	condominium buildings sustained major damage
2	townhouse buildings sustained major damage
1	motel end unit destroyed
5	motel structures sustained major structural damage
1	cabana recreation building destroyed
5	pools destroyed
3	pools sustained major damage
3	fishing piers destroyed
2	fishing piers sustained major structural damage
103	major structures destroyed or sustained major damage

MANATEE COUNTY

1,480	ft. bulkheads destroyed or sustained major damage
350	ft. boulder-mounds or rock revetments destroyed or sustained major damage
4	groins sustained major damage
4	single-family dwellings destroyed
9	single-family dwellings sustained major damage
3	condominium buildings sustained major damage
1	motel building sustained major damage
17	major structures destroyed or sustained major damage

SARASOTA COUNTY

905 ft. bulkheads destroyed or sustained major damage
3,800 ft. paved road damaged
1 single-family dwelling destroyed

TOTAL MAJOR STRUCTURAL DAMAGES

165 Major Structures (excluding roads)
21,095 ft. (4 mi.) Bulkheads
680 ft. Boulder-mounds or Revetments
200 ft. Retaining Walls
37,980 ft. (7.2 mi.) Roads (excluding U.S. 98)

SUMMARY OF STRUCTURAL DAMAGES, TROPICAL STORM JUAN

ESCAMBIA COUNTY

1 motel of 56 units with 27 units destroyed and 29 units damaged

BAY COUNTY

100 ft. bulkhead destroyed
100 ft. retaining wall destroyed

PINELLAS COUNTY

1,525 ft. bulkheads destroyed or sustained major damage
3,450 ft. concrete block retaining walls destroyed
3 single-family dwellings destroyed
4 single-family dwellings sustained major damage
1 condominium building sustained major damage
1 motel/apartment building unit destroyed
1 motel sustained major damage
3 pools destroyed
3 pools sustained major damage
16 major structures destroyed or sustained major damage

MANATEE COUNTY

1,665 ft. bulkheads destroyed or sustained major damage
40 ft. concrete block retaining wall destroyed
440 ft. bulkheads sustained minor damage
2 groins sustained major damage
1 single-family dwelling destroyed
4 single-family dwellings sustained major damage
1 pool destroyed
1 pool sustained major damage
7 major structures destroyed or sustained major damage

SARASOTA COUNTY

750 ft. bulkheads destroyed or sustained major damage
300 ft. bulkheads sustained minor damage

LEE COUNTY

1 single-family dwelling destroyed on Captiva Island
1 motel unit destroyed on Sanibel Island

TOTAL MAJOR STRUCTURAL DAMAGES

26 Major Structures (excluding roads)
4,040 ft. Bulkheads
3,590 ft. Retaining Walls

DAMAGE TO MAJOR STRUCTURES

Although the damage to coastal construction in Florida from hurricane Elena and tropical storm Juan was substantial and widespread, neither storm brought with it the type of impact expected from a shore incident hurricane. A shore incident hurricane would typically cause an array of modes of damage due to the maximum wind and water forces crossing the coast and extending inland.

The damage sustained from both storms along the southwest coast of Florida was generally limited to a narrow band along the immediate shorefront on the Gulf of Mexico and nearly all of the significant damage was due to the storm tide and wave activity as opposed to any winds. Where beaches existed, the damage to structures was the least. Where beaches were narrow or nonexistent, the damage to bulkheads and buildings was extreme considering the far away location of the storms' eyes.

The damage sustained along the northern Gulf coast of Florida was generally dependent on the nearness of the storm centers to the areas impacted. Cedar Key's damage occurred with the stall of Elena immediately offshore while Franklin County sustained most of its damage when Elena swept along and just offshore. The Dunes Motel collapse on Pensacola Beach occurred during Juan's fringe impact on Escambia County, yet the final damage was set up by Elena's prior offshore pass and initial damage.

Elena's widespread shorefront damage was not surprising given the strength of the storm and the duration of the storm as it sat offshore subjecting the coast to high energy storm wave activity for two days. On the other hand, Juan's impact, primarily to the southwest Florida coast, was a major surprise given the far away location of the eye. Juan did have a very large size affecting the entire basin of the Gulf and subjecting even the distant northwest shoreline of Cuba with its wave energy.

The dwellings damaged and destroyed between the Southwest Cape and Lighthouse Point were not designed for storm tide, wave, or erosion conditions of a major storm. The slab-on-grade concrete block dwellings and the wood frame dwellings on footings were totally inappropriate for an exposed eroding Gulf front shoreline. None of the dwellings would have been damaged had they been constructed on pile foundations of sufficient height, penetration, and pile diameter. The one pile supported dwelling which was destroyed at the Southwest Cape had insufficient pile penetration allowing the storm waves to knock out the piles once they lost the supporting soil around them. The damaged dwelling at Lighthouse Point was also situated on short piles which collapsed when the dwelling was undermined. The low elevations

and inadequate foundations were the problems of the damaged Lanark and Carrabelle Beach structures which should have been elevated and situated on piles of sufficient depth. So it is essential for beach dwellings to not only be supported by piling but for the piles to penetrate a sufficient depth below the eroded grade to provide adequate support under direct wind and wave loads on the structure. It is also essential for foundation piles to be of adequate diameter and to be sufficiently braced when exposed above grade.

Even the dwellings protected by rigid coastal protection structures such as bulkheads and revetments should be supported by substantial pile foundations of adequate penetration. None of the habitable major structures destroyed or damaged by Elena and Juan on the southwest Gulf coast had adequate elevations and foundations. Large numbers of other structures which survived solely because the bulkhead or revetment did not fail may someday reveal the inadequacy of their foundations when subjected to a shore-incident major hurricane which destroys their weakened coastal protection structure.

DAMAGE TO COASTAL PROTECTION STRUCTURES

Seawalls are large, massive, coastal protection structures designed to withstand storm wave impact loads and are generally designed for a 20 to 50 year frequency storm event or greater. Nearly all the walls in Pinellas County are bulkheads and not seawalls. Although the primary purpose of a bulkhead is to retain the upland fill, bulkheads are generally designed for moderate to heavy wave activity. That the Gulf front bulkheads of Pinellas County should be commonly referred to as seawalls is a result of the changing purpose for which these walls have been subjected. Where the beach has eroded, the bulkhead now has to provide the upland property owner protection from all tide and wave conditions. Unfortunately, a bulkhead does not have the same design protection capability as a massive seawall. Retaining walls, usually small structures of a frangible or breakaway nature, have a lower load capability than bulkheads, yet even unreinforced concrete block retaining walls of low elevations are labeled seawalls by property owners who desire ultimate protection by such structures.

The vertical bulkhead is the most common coastal protection structure in Pinellas County while the boulder-mound and the rock revetment are the most common coastal protection structures in Manatee County. Numerous groins aligned perpendicular to the shoreline exist in these areas, however, such devices are termed shore protection structures as opposed to coastal protection structures because they are designed to protect the shore or beach. Revetments, boulder-mound structures, and bulkheads also exist in Franklin County.

The most natural of coastal protection structures are man-made dunes and the natural sand dunes themselves. Natural dunes dominate the barrier beaches across the Florida Panhandle coast from Escambia to Wakulla County. The Cedar Keys and the public land islands of Pinellas County are also dominated by sand dune formations. Northern Clearwater Beach Island has dunes but development has generally replaced the dunes along the remainder of the island. Throughout Sand Key where structural damage was the greatest the natural dunes have been destroyed by development. Although technically much of the barrier dune formation exists while covered with asphalt, concrete, wood, and ornamental plantings, the natural erosion and accretion function of the dune system has been altered to the point that there is no longer any resemblance to a natural system.

The same overdevelopment and dune damage occurred along Treasure Island and Long Key which now have beach restoration projects. In areas of Treasure Island, the City of Treasure Island has constructed dunes and stabilized them with sea oats. Although

Elena and Juan caused minor erosion to these man-made dunes and damaged some of the sea oats, these dunes provided adequate storm protection to the properties behind them. The damage areas of Manatee and Sarasota Counties south of Tampa Bay have also seen overdevelopment destroy all the natural dunes.

There is no questioning the fact that the most efficient coastal protection is a natural beach and dune system. The distribution of damage resulting from Elena and Juan only serves to further confirm this. As previously discussed, where beaches existed, the damage to structures was the least. And where beaches were narrow or nonexistent, the damage to bulkheads and buildings was extreme. The solution to minimizing the future storm damage in the areas substantially damaged by Elena and Juan is to renourish the beaches in these areas.

Along Sand Key where the beaches are narrow even when renourished, the bulkheads are depended upon heavily for coastal protection from storm tides and waves. Most of the bulkheads which were destroyed when subjected to the waves of Elena and Juan were old walls of inferior construction and design. Cap elevations were too low, caps were not adequately designed, tie-backs were missing or inadequate, return walls were missing, and wall penetration was insufficient; however, the most significant problems affecting all the damaged bulkheads were the lack of toe-scour protection and the lack of fill containment.

Had adequate rock toe-scour protection existed, walls would not have been undermined and storm wave energy would have been dissipated without the excessive wall damage which occurred. Only two properties on Sand Key had toe-scour protection and they sustained no damage to the bulkheads protected by the rock. The bulkhead with toe-scour protection at the 50 Gulfside Condominium in Indian Rocks Beach performed as designed (Figures 99 and 100) while the adjacent unprotected bulkheads were destroyed (Figures 97 and 98). The bulkhead with toe-scour protection at the Montmarte Apartments in Belleair Beach was undamaged by either storm (Figures 52 and 54). Figure 53 shows the rapid recovery of the beach during the normal wave conditions after the storm erosion of Elena, while bulkheads with no toe-scour protection remained without beach recovery due to the continued wave reflection off the vertical walls.

The increased beach erosion conditions due to wave activity on vertical bulkheads is well documented; however, there continues to be a wide spread misunderstanding of this generally accepted phenomena. It is fortuituous that Bodge and Kriebel presented a comparison of profile data after Elena further confirming this wall impact effect. A comparison of the two Elena eroded profiles with and without the vertical bulkhead reflects a volumetric balance over the entire profiles; however, the volume

loss on the profile with the bulkhead was concentrated at a location seaward of the wall resulting in the complete loss of the beach (Figure 51). On the profile without the bulkhead, the entire profile eroded evenly with the upland or dune erosion reducing the volume of beach erosion. With the natural beach and dune system the profile adjusts to the storm beach profile, usually to recover completely under normal post-storm conditions. With the bulkhead located wihin the active beach system the dune material is isolated from nourishing the beach and from being transported seaward to the storm wave built bar. Without the dune sediment required to build the bar, additional material is removed from the beach seaward of the bulkhead. If the beach profile is lowered below sea level and if longshore transport does not contribute sufficient material for accretion seaward of the bulkhead, post-storm normal wave activity can prevent any beach recovery by maintaining a scoured profile caused by the constant wave reflection off the vertical wall.

With rock toe-scour protection to dissipate the wave energy, the profile may accrete if there is sufficient sediment available. Without an overburden of sediment available on the profile to accrete the beach, the shoreline will suffer from the stress of constant wave activity. Unlike rock mounds and revetments, reinforced concrete bulkheads cannot withstand a constant breaking wave attack for an unlimited duration.

A large percentage of the bulkheads destroyed on Sand Key from Belleair Beach through North Redington Beach would have withstood the storm wave impact of Elena and Juan had the upland fill landward of the walls been adequately containerized. Waves overtopping the low wall cap elevations scoured substantial quantities of sediment behind the walls leaving the bulkheads free standing walls and incapable of withstanding the high loads accompanying the impact of breaking waves (Figure 64). Some low bulkheads in Holmes Beach could not withstand the storm waves impact even behind toe-scour protection once the loss of backfill left them free standing (Figures 132 and 134).

Many bulkheads constructed in recent years along Sand Key were not designed for compressive loads. Some walls had substantial tiebacks encased in concrete and even though the wall lost much of its backfill there was minimal damage. But in some cases the backfill loss was so great that even walls with tiebacks encased in concrete failed, as occurred at the Tortugas Condominium in Belleair Beach with the wall collapsing outward instead of breaking and falling inward (Figure 58).

Lack of fill containment was also a problem in Manatee County where there was substantial wall damage from Elena and Juan (Figure 127). In most cases boulder-mounds and revetments provided adequate protection; however, a few such structures

failed in Manatee and Franklin Counties from settlement because there was no geotextile foundation present (Figure 28).

GUIDANCE FOR RECONSTRUCTION

With the impact of Elena and Juan put into perspective, the task of reconstruction should be given more thought than what has been observed during the past several months. It is to lament that many structures are simply being replaced or repaired in the same manner or design as the original structures even though the sole cause of their failures was due to their design inadequacy. There is, however, a trend to more substantial structures. In addition, the newness of many replacement structures will in itself mitigate future damages by comparable storm conditions.

In north Florida, where Franklin and Escambia Counties received the most impact to major structures, a coastal building code to be adopted by the local governments became effective on March 1, 1986. Construction and design to the state required coastal building standards will substantially mitigate future storm damages in general and will more than adequately mitigate against any major damage to new habitable major structures caused by comparable conditions which occurred during Elena and Juan in Florida. Unfortunately, these coastal building standards will not apply to the St. George Sound shoreline where numerous inadequately designed residences were destroyed by Elena. In addition, the coastal building standards do not address the siting of structures and therefore it is important that new coastal construction control lines be established in Bay, Okaloosa and Escambia Counties to address this problem. The coastal barriers of Franklin and Walton Counties now have adequate control lines to address siting. A new control line was just established in Gulf County; however, the construction of numerous structures was initiated prior to control line establishment to intentionally circumvent both the State's siting requirements and coastal building standards. The promotion of inadequately designed and sited structures by the local government of Gulf County is typical of many coastal counties and communities of Florida and is why the Florida Legislature adopted specific statutory changes to address these problems. Should the Legislature subsequently provide the funding necessary to administer these new laws, the adoption of new coastal construction control lines would address the siting problems and the coastal building standards would also be enforced.

Not addressed by the former or new statutes is the issue of coastal road protection. In addition, generic policies are not always equitably applied to specific problem sites. Many of the vulnerable coastal road sites are too close to the shoreline while others are simply too low and without any natural protective barriers. Land costs and available funds are always the key to evaluating road relocation in comparison with reconstruction or protection. The accelerated coastal growth

with inflated land values has made road relocation a high cost solution. Additionally, the acquisition or condemnation proceedings make untimely any road relocation solution.

Historically the Florida Department of Transportation has chosen to armor vulnerable stretches of damaged roadway in lieu of relocating the road. Such has again been the decision in reconstructing U.S. Highway 98 in Franklin County that was extensively damaged by Elena. The success of revetment construction along U.S. Highway 98 will be measured by future storm impact as well as by the cost of future road relocation projects. Post-Agnes road reconstruction was definitely the least cost alternative in 1972; however, the Elena damage has now been added to that cost thus making relocation at lower land values appear in hindsight to be more attractive.

None of the alternatives will always prove to be a permanent solution. For example, a landward relocation of many barrier island roads simply will not prevent them from being damaged by storm surge overtopping. In addition, barrier dune restoration or revetment construction will eventually be subjected to storm conditions which exceed their design protection capability. A major problem with post-storm road protection projects is their design inadequacy resulting in part from inadequate funding and in part from a non-coastal engineering technology being applied by the highway engineering departments of local governments and the State. The dumping of small rock and concrete rubble is frequently the first solution proposed by road maintenance staffs due to the available supply of such debris and due to the lack of funds to construct an adequately designed coastal protection structure.

While relocation of roads usually necessitates the acquisition of new land, the relocation of single-family dwellings is often a recommended option to a coastal landowner who has sufficient available space to accommodate a relocation. Frequently a minor relocation of a dwelling accompanying the reconstruction of a foundation can mitigate most expected storm conditions. Although little can be done for slab-on-grade, concrete block dwellings, grade level wood frame dwellings should be relocated landward and elevated on wood pile foundations. There remains a limited number of grade level wood frame dwellings on Alligator Point. Because these are older structures and are generally not constructed for wind velocities in excess of 100 miles per hour, high elevations above grade could subject them to damaging loads. Elevating these dwellings approximately eight feet above grade where the existing grade elevation varies from +5.0 feet NGVD to +8.0 feet NGVD should provide sufficient protection from most any expected storm surge and wave conditions without placing the structures too high for severe wind loads. Metal straps should be added to tie down the roof trusses if possible, and strapping

or metal plates should be incorporated into the connections between the superstructure and the foundation.

The same recommendations for grade level wood frame dwellings on Alligator Point apply to similar such structures on the lower Gulf coast. The more capable the structure is for wind loads, the higher it may be safely raised above grade. The design nature of the building generally limits the degree to which a new and adequate foundation can be implemented. For monolithic reinforced concrete buildings, such as numerous beach motels or condominiums, foundation repair or reconstruction may be difficult if not impossible without gutting the superstructures and employing radical foundation construction techniques. The high cost and the time frame the structure would be rendered nonhabitable make such an option highly unpopular to the property owners. Armoring is usually the popular option when a major structure on a soil bearing foundation is threatened by continued erosion conditions. Such a solution is also the most impactive to the beach system and may likewise be impactive to the adjoining properties should the plan call for an isolated rigid coastal protection structure.

When there is no viable alternative to protecting a large building than through the construction of an isolated rigid coastal protection structure, the regulatory issues of upland protection versus impact to the beach and adjoining properties become a topic of major controversy. When a bulkhead or revetment is proposed on an alignment consistent with and connecting to existing adjoining structures of similar design capability and when such a proposal will close a gap in an otherwise continuous length of armored coast, the issue of adjacent property impact is eliminated and the beach impact issue is lessened. Along the extensively damaged shoreline of Belleair Beach, Belleair Shore, Indian Rocks Beach, Indian Shores, Redington Shores and North Redington Beach an almost continuous line of bulkheads exist. With the exception of Indian Shores, reconstruction of bulkheads on the alignments recommended by the Department's engineeering staff was generally without major controversy. Unfortunately, property owners in Indian Shores appeared more concerned with circumventing reasonable design guidance, and the resulting alignment of the reconstructed bulkheads located immediately landward of the coastal construction control line departed from the already noncontinuous alignments of the bulkheads which survived Elena and Juan.

As previously discussed, the lack of toe-scour protection and fill containment were the most common problems afflicting the damaged bulkheads in south Florida. There were a variety of other design and construction problems leading to the failure of many bulkheads. Among these were low cap elevations, inadequate wall embedment, inadequate cap design, tiebacks were missing or

inadequate, return walls were missing, and inferior materials were used. Belleair Shore, Indian Rocks Beach, and Redington Shores acted responsibly in reviewing and revising their bulkhead design requirements based on the advice of coastal engineering consultants and the Department's engineering staff. Such was not the case in Belleair Beach and Indian Shores; however, some individual properties in these communities did adopt bulkhead design proposals based on reasonable coastal engineering design guidance.

For minimum design guidance, the adopted requirements of Belleair Shore, Indian Rocks Beach and Redington Shores are highly recommended. These bulkhead requirements call for tongue and groove reinforced concrete slabs with poured-in-place concrete caps. Noteworthy among the requirements are a minimum length of concrete slabs of 16 feet and a minimum thickness of concrete slabs of 8 inches. Both vertical and horizontal reinforcing steel is necessary. The poured-in-place concrete cap should have a width of approximately 24 inches and a depth of approximately 18 inches. The embedment of the concrete slabs into the cap should be approximately 8 inches.

Along Sand Key, bulkhead cap elevations should reach at least +8.0 feet NGVD; however, higher elevations for greater shoreline lengths will provide greater protection from wave overtopping. With higher bulkhead cap elevations, higher elvations will also be needed for the rock toe-scour protection. Generally a crest elevation of +5.0 feet NGVD to +6.0 feet NGVD will be adequate for the rock and a toe elevation of below 0.0 NGVD will be sufficient given the availability of any beach slope seaward of the bulkhead. In difficult scour cases, such as, along the north shore of Clearwater Pass and adjacent to the Martinique Condominium's wall in Manatee County, a lower foundation elevation becomes a necessity. At such problem sites a greater thickness of bedding stone is recommended atop a nonwoven polypropelene geotextile to compensate for the lower toe elevation and greater exposure to wave and current turbulence.

Where no beach exists seaward of the bulkhead, large rocks weighing between 500 and 3,000 pounds should be used to dissipate the incident wave energy. A slope of no greater than one vertical to two horizontal should also be incorporated into the design of the toe-scour protection. Although the toe-scour protection structure will provide a substantial protection against repetitive wave loading, the bulkhead's tieback design is also critical to prevent shear failure of the bulkhead slabs. While minimum guidance dictates encasing the steel tieback rods with epoxy or an equivalent protective compound, it is highly recommended to additionally encase the tieback rods in an 8 inch by 8 inch concrete beam to withstand the compressive loads to which the bulkhead will be subjected when under storm wave attack

(Figure 59). Tiebacks should be at least 15 feet in length; however, lengths of 20 feet or greater will provide less compressive strength due to their flexure. A tieback length of between 15 and 18 feet should be sufficient provided a system of adequate fill containment is employed behind the wall.

The tiebacks should connect to concrete deadmen having a minimum vertical surface area of between 7 and 10 square feet. At locations where the bulkhead cap is very low and extensive scour is expected landward of the wall during storm surge overtopping, the deadmen should be supported by a single pile. Such a design feature was employed by the Department of Transportation in the bulkheads of the St. George Island causeway, and when segments of this bulkhead were destroyed by Elena many of the concrete deadmen remained standing even when several feet of scour occurred below them (Figures 14 and 15).

Where bulkheads do not connect with existing adjoining walls, a return wall of comparable design is necessary. Even along stretches of continuous bulkheads return walls are needed at approximately 200 foot intervals. Along these continuous bulkheaded stretches, return walls should have lengths of at least 40 to 50 feet. Longer return walls may be necessary at the ends of bulkheads. In such cases, toe-scour protection may also be needed adjacent the return walls depending upon the degree of exposure to flanking wave attack.

When a bulkhead loses the supporting material behind it, the structure is generally not capable of withstanding the repetitive loading of breaking storm waves. As previously discussed, many of the bulkheads on Sand Key from Belleair Beach through North Redington Beach would have withstood the storm wave loads had the upland fill landward of the wall been adequately containerized. Some low bulkheads in Holmes Beach were destroyed even behind toe-scour protection structures once they were left free standing due to the loss of backfill. The generally accepted practice of using only strips of filter fabric behind the tongue and groove seams has provided for runoff and wave splash filtration, but is totally inadequate for significant wave overtopping. It is highly recommended that the sand backfill be containerized for a minimum distance of 25 feet behind the walls. After excavating the area behind the wall a woven geotextile may be placed down the back of the bulkhead to approximately 0.0 NGVD and then landward and up the backslope created by the excavation. Clean sand fill, free of roots, debris, and rubble, should then be backfilled over the fabric. The fabric then should be extended landward from the wall over the backfill and seaward from its landward limits over the backfill and sewn or stapled together creating a giant sandbag type container of sand.

It is essential that all remnant slabs, rubble, and debris be removed from landward of the wall to allow for fill contain-

erization without damaging the fabric. To the extent that such objects can be relocated a sufficient distance away from the wall, their burial on-site will probably not create any other major problems. The use of material other than clean sand fill behind the wall can cause problems relating to the undesirable buildup of hydrostatic pressure. Clayey, silty, or organic materials do not have the permeability needed to release the water entrapped behind the bulkhead. A classic bulkhead failure occurred on the northeast coast of Florida in the late 1970's when a simple 1 inch water line broke and the wall could not withstand the buildup in hydrostatic pressure which resulted.

The use of the area immediately landward of a bulkhead frequently creates problems. Concrete slabs or asphalt paving should not be located immediately landward of bulkheads. If the backfill is adequately containerized a 6 to 14 inch layer of top soil may be added and stabilized with grass. Given their substantial root system and resistance to salt spray, sea oats are the best plant material to use in stabilizing the soil behind a bulkhead. However, grass and low ornamental plants are an acceptable alternative in this situation and are generally preferable to the property owners in these highly developed areas. Walkways and decks, when located behind bulkheads, should be of wood construction and should be capable of being easily removed in sections to facilitate the repair or inspection of the tiebacks. In addition, trees should not be planted within 25 feet of bulkheads.

Unlike the bulkheads of Pinellas County, the boulder-mounds and revetments of Manatee County and Sarasota County experienced very little damage from Elena and Juan. Some minor settlement problems and dislodging of armor stones can be solved most easily through the placement of additional rock. Care should be taken in the placement of the additional rock so that the structure's slope does not exceed one vertical to two horizontal. In the few cases where the structures failed from settlement because there was no geotextile foundation, a total reconstruction of the structure is necessary.

The lack of experienced contractors and the general unavailability of prepared construction materials has been a major obstacle to the reconstruction effort experienced since Elena and Juan. Hopefully, the implementation of some of the design guidance that has been discussed in this document will assist in mitigating future damages by comparable and worse storm conditions. Should the lower Gulf coast of Florida experience a shore incident hurricane, substantially greater damage than that experienced from Elena and Juan will occur. The most effective defense to mitigate the damages from such an impending disaster is to renourish the beaches in the vulnerable areas.

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