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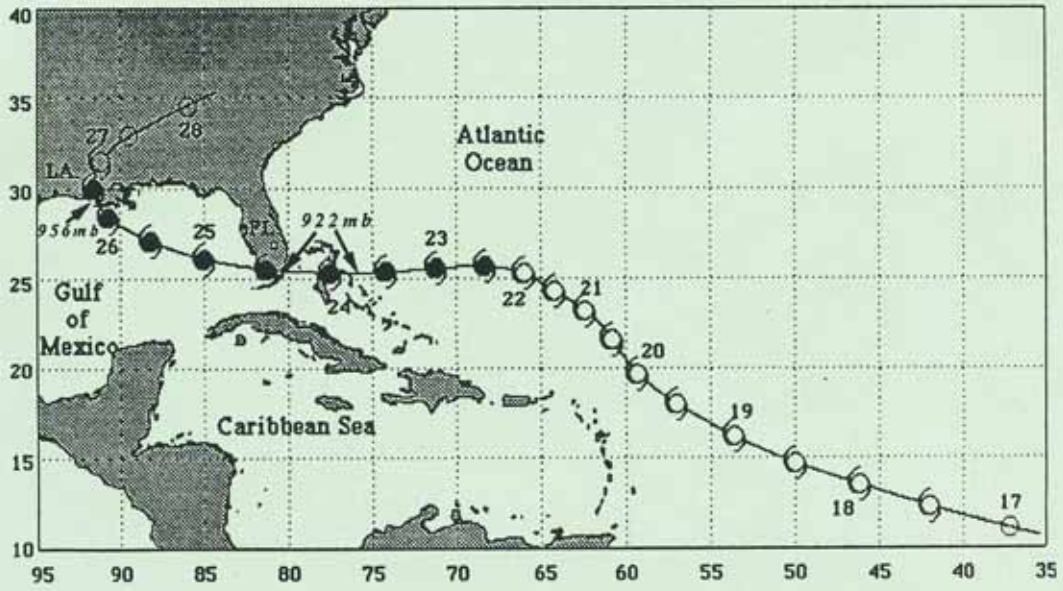
HURRICANE ANDREW STORM SUMMARY AND IMPACTS ON THE BEACHES OF FLORIDA SPECIAL REPORT



US Army Corps of Engineers
Jacksonville District

Florida Department of Natural Resources
Division of Beaches and Shores

PREFACE

The information and data presented herein were assembled and analyzed during August through December 1992, following Hurricane Andrew, by authorization of the Coast of Florida Erosion and Storm Effects Study. The feasibility cost sharing agreement of the study between the Jacksonville District U.S. Army Corps of Engineers (USACE) and the Florida Department of Natural Resources (DNR), Division of Beaches and Shores calls for post storm data collection and analysis.

The study is a multi year effort of the Jacksonville District and the DNR, under general supervision of Mr. A. J. Salem, Chief, Planning Division, Jacksonville District and Mr. Kirby Green, Director of the DNR, Division of Beaches and Shores. Mr. Mitch A. Granat and Mr. Ralph R. Clark are the Coast of Florida study managers for the Corps and DNR, respectively. This report was prepared by Mr. David V. Schmidt, Chief Coastal Section, Plan Formulation Branch, Planning Division, Jacksonville District, Ms. Kimberley A. Taplin, Coastal Section, Plan Formulation Branch, Planning Division, Jacksonville District and Mr. Ralph R. Clark, Florida DNR, Division of Beaches and Shores.

A special acknowledgment is due Mr. Andrew W. Garcia, USACE Waterways Experiment Station and Mr. Tom Watters, Florida DNR, Division of Beaches and Shores for their untiring efforts in acquiring and assembling the high-water mark data and interpretive guidance.

The hurricane track diagram presented on the cover was reprinted with permission from the National Oceanic and Atmospheric Administration's (NOAA) Hurricane Research Division, Miami, Florida. The data shown on the diagram are from the National Hurricane Center's preliminary report.

The Commander of the Jacksonville District during the conduct of this study and report was Colonel Terrence C. Salt, USA. The Executive Director of the Florida Department of Natural Resources was Ms. Virginia B. Wetherell.

MAY 1993

HURRICANE ANDREW STORM SUMMARY
IMPACTS ON THE BEACHES OF FLORIDA
SPECIAL REPORT

1. This report summarizes the cooperative actions of the U.S. Army Corps of Engineers Jacksonville District (USAED, JAX) the Florida Department of Natural Resources (DNR), Division of Beaches and Shores, and the U.S. Army Corps of Engineers Waterways Experiment Station, Coastal Engineering Research Center (CERC) with respect to determining the impacts of Hurricane Andrew on the beaches of south Florida. The authority for this report is provided by the feasibility cost sharing agreement for the Coast of Florida Erosion and Storm Effects Study between the Corps and the DNR. The agreement calls for post storm monitoring and data collection after significant storm events in Florida.

BRIEF STORM SUMMARY

2. On August 17 at 8:00a.m., tropical storm Andrew was born. Andrew became a hurricane on August 22 at 8:00 a.m. The center of the eye of Hurricane Andrew made landfall near Florida City, 25 miles south of downtown Miami, at 4:52 a.m. on 24 August 1992 with sustained winds at the eye wall of 145 miles per hour (mph) and gusts up to 175 mph. Figure 1 is a location map at landfall. Satellite images of the hurricane at landfall are shown in Figures 2 and 3. At 7:30 a.m., after traveling westward over south Florida, the storm passes over Marco Island on Florida's gulf coast and into the Gulf of Mexico. The path of Hurricane Andrew is shown in Figure 4. The position of the storm at landfall from the Miami Herald is shown in Figure 5, and also depicts the locations of the affected communities.

WIND SPEEDS

3. According to the National Hurricane Center, the sustained wind estimates are probably low by as much as 20 percent since every anemometer in the strongest wind areas failed during the storm. Wind gusts over 200 mph may have been experienced based upon observations of damage by structural engineers and wind experts. An Air force hurricane reconnaissance plane at 10,000 foot altitude at the approximate time of landfall measured sustained winds at 187 mph with gusts of 196 mph. Andrew had a barometric pressure of 27.34 inches at landfall. The northern part of the eye of the storm passed over the National Hurricane Center in Coral Gables, located about 20 miles north of Florida City. The rainfall at Miami International airport for the two days of 23-24 August 1992 was 0.33 inches. The next ten days,

5.34 inches of rain was recorded at the airport. Wind speeds at various locations in Broward and Dade Counties are shown in Tables 1 and 2. The locations of the recorded wind speeds are displayed in Figures 6 and 7, respectively. Figure 8 shows a time series plot of barometric pressure, wind direction and wind speed for the National Data Buoy Center gage at Fowey Rocks. The gage location is shown as flag number 141 on the map locating wind speeds for Dade County (Figure 7).

4. A panel convened at the 1992 annual meeting of the American Meteorological Society in Anaheim, California, concluded that Andrew's top winds were 140 to 145 mile per hour sustained winds with 170 to 180 miles per hour gusts. Mr. Ted Fujita of the University of Chicago in his paper to the Society indicated he discovered previously unknown vortices that ripped along short curved paths creating winds of as much as 200 miles per hour. These winds according to Mr. Fujita became Andrew's most destructive winds and explain sporadic and narrow bands of damage within the storm. The vortices formed because of variations in the eye wall and gained speed as the air was pulled upward and spun tighter. He found that many of the wind spirals that ripped Dade County spun clockwise, not counterclockwise as most tornadoes do in the Northern Hemisphere. He also found that the damage wasn't in streaks, but in boomerang-shaped swaths. The vortices, lasting 10 seconds or less, spun at 80 miles per hour, but they were pushed by 120 mile per hour winds, giving them the force of 200 mile per hour. (Source, Miami Herald, January 21, 1993).

SURGE LEVELS

5. The surge levels reported for the hurricane are shown in Table 3. The locations for the surge elevations are displayed in Figure 9. These surges compare fairly well with the predicted surges for a category 4 storm from the Flood Insurance Study for Dade County (FEMA, 1987) shown in Figure 10. The Bakers Haulover Inlet tide gage record is shown in Figure 11. Historically, drownings due to surge and flooding account for 90 percent of hurricane deaths. For Hurricane Andrew, these deaths only account for 13 percent of the total. This is due in part to the location of landfall, the coastline of which was in a lightly developed area. The landfall area from S.W. 184th Street (Eureka Drive) to Turkey Point has 90 percent of the fringing mangroves left in Dade County. The area's natural resources are depicted in Figure 12. A cross-section of the surge profile along the shoreline on Key Biscayne at the time of storm landfall is shown in Figure 13.

TABLE 1
WIND SPEEDS - BROWARD COUNTY

	Location	Top Gusts (MPH)
1.	Palm Beach International Airport	54
2.	Boca Raton Middle School	58
3.	Private Home	90
4.	Goodyear Blimp Base	100
5.	Private Home	105

Locations are identified by number in Figure 6.

TABLE 2
WIND SPEEDS - DADE COUNTY

	Location	Sustained Winds (MPH)	Top Gusts (MPH)
1.	Haulover Beach	67	98
2.	Miami Beach	74	106
3.	320 N.W. 132nd Ct.	78	96
4.	Virginia Key	85	98
5.	Miami International Airport	86	115
6.	Fowey Rocks	141	169
7.	National Hurricane Center	115	163
8.	Turkey Point	N/A	160

Locations are identified by number in Figure 7.

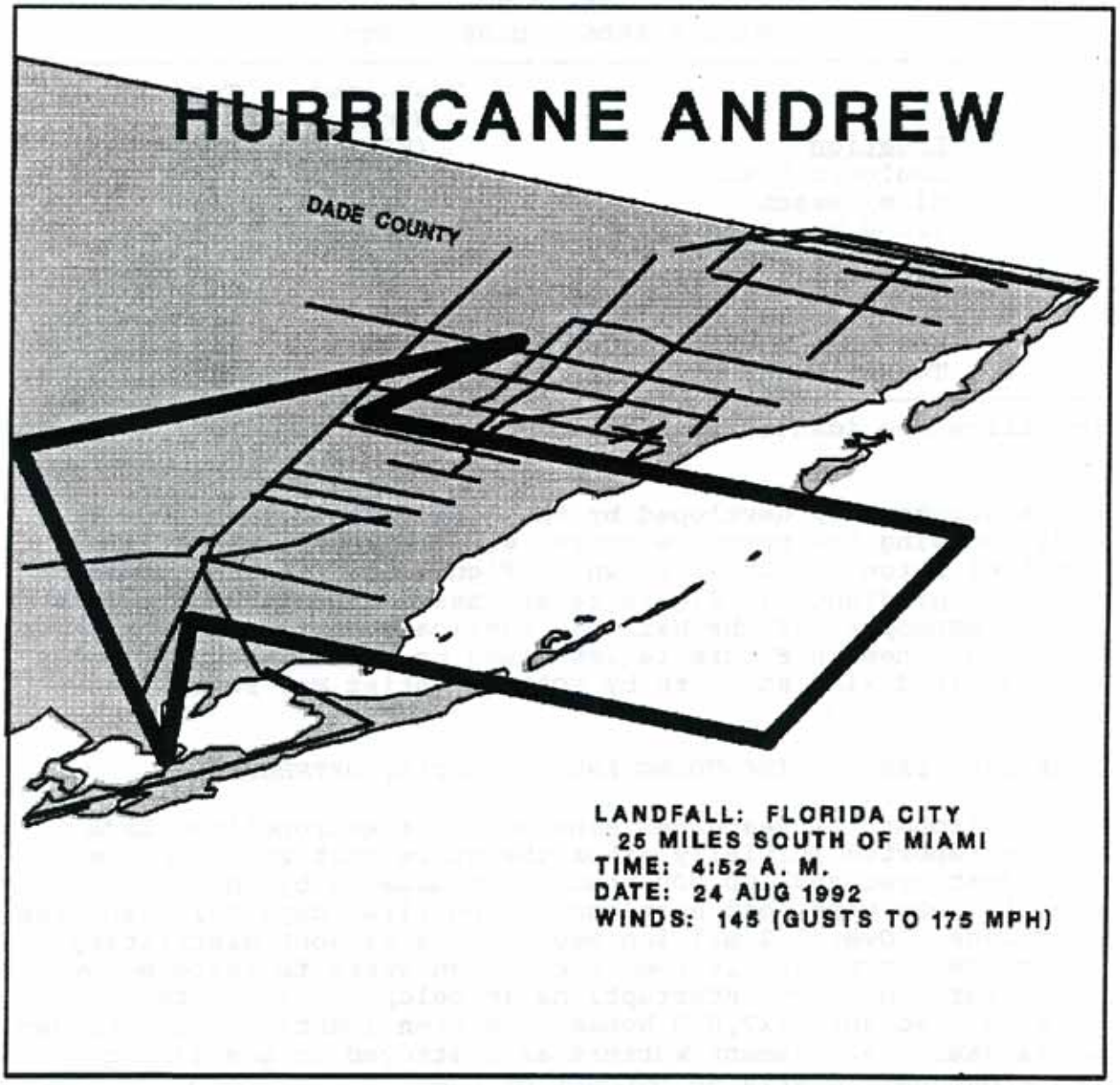
6. A summary map developed by the Miami Herald (December 20, 1992) showing the pressure zones, wind contours, and inland limit of surge impact is shown in Figure 14. The barometric pressure gradients in Figure 14 are based on data analyzed by Mr. Ed Rappoport of the National Hurricane Center in Miami. The wind zones in Figure 14 are based on preliminary estimates of sustained wind strength by NOAA scientist Mr. Peter Black.

HURRICANE DAMAGE, INCLUDING ENVIRONMENTAL, OFFSHORE

7. Environmental Resources Management of Metropolitan Dade County reported initially after the storm that 25,000 homes were destroyed and 100,000 homes were damaged by the storm. Over 125,000 were left homeless in the first days following the hurricane. Over 1.3 million people were without electricity after the storm, and it took over seven weeks to restore power. There were numerous interruptions in telephone and water service. Roughly 117,000 homes have been identified by the Red Cross damage assessment workers as destroyed or sustaining major damage. Nearly 90 percent of the

FIGURE 1

LOCATION MAP



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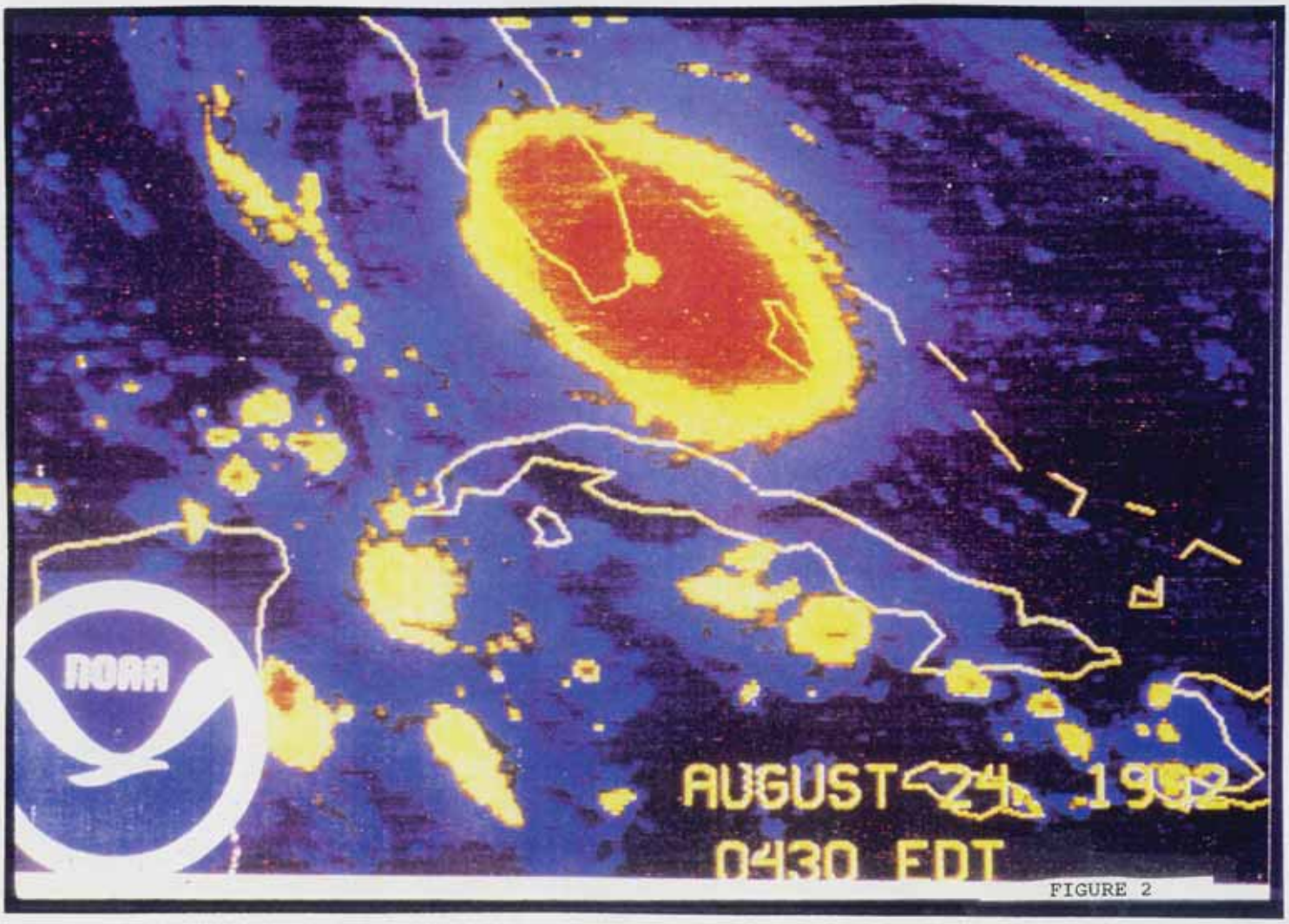


FIGURE 2

FIGURE 3
SATELLITE IMAGE

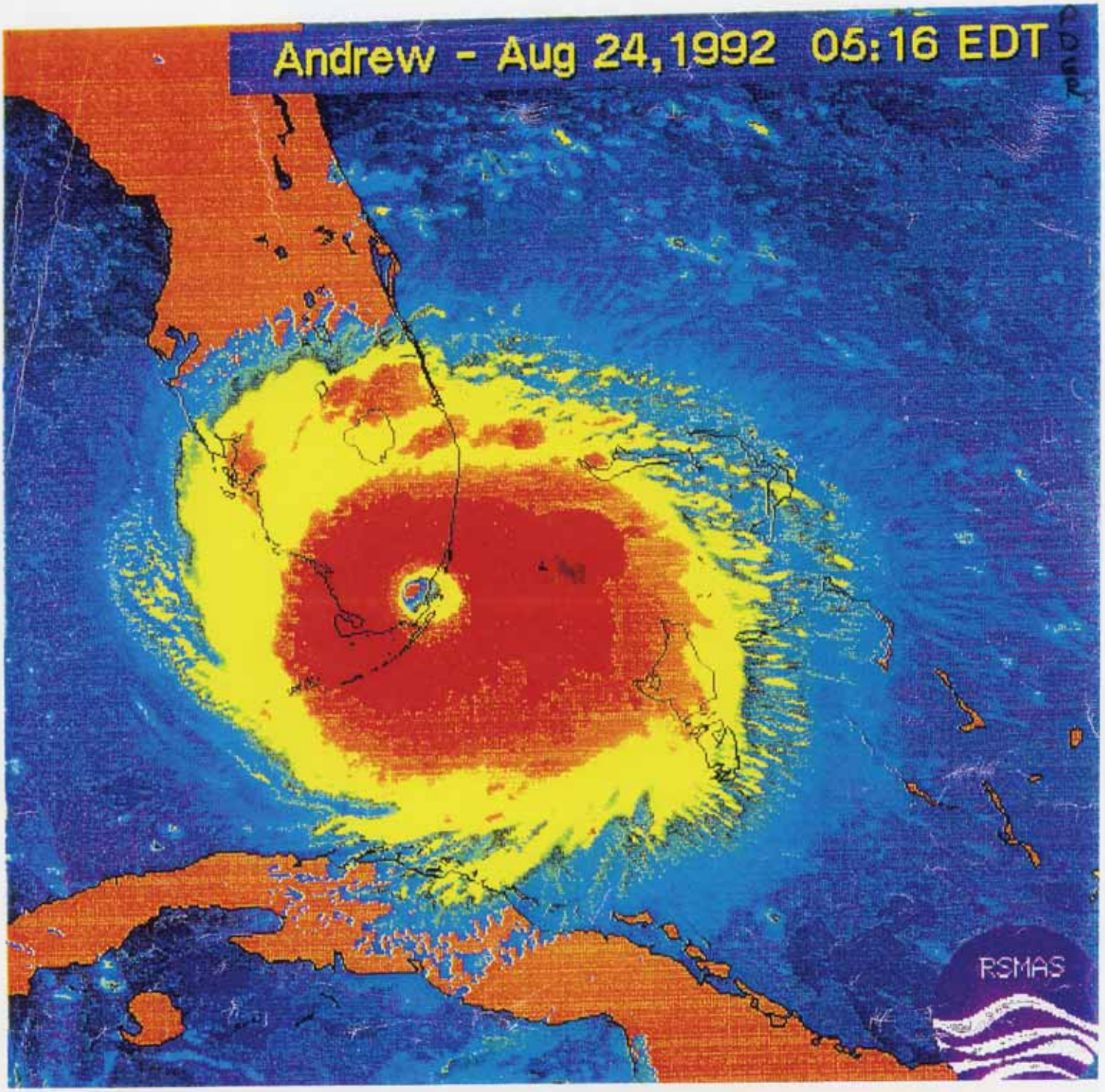
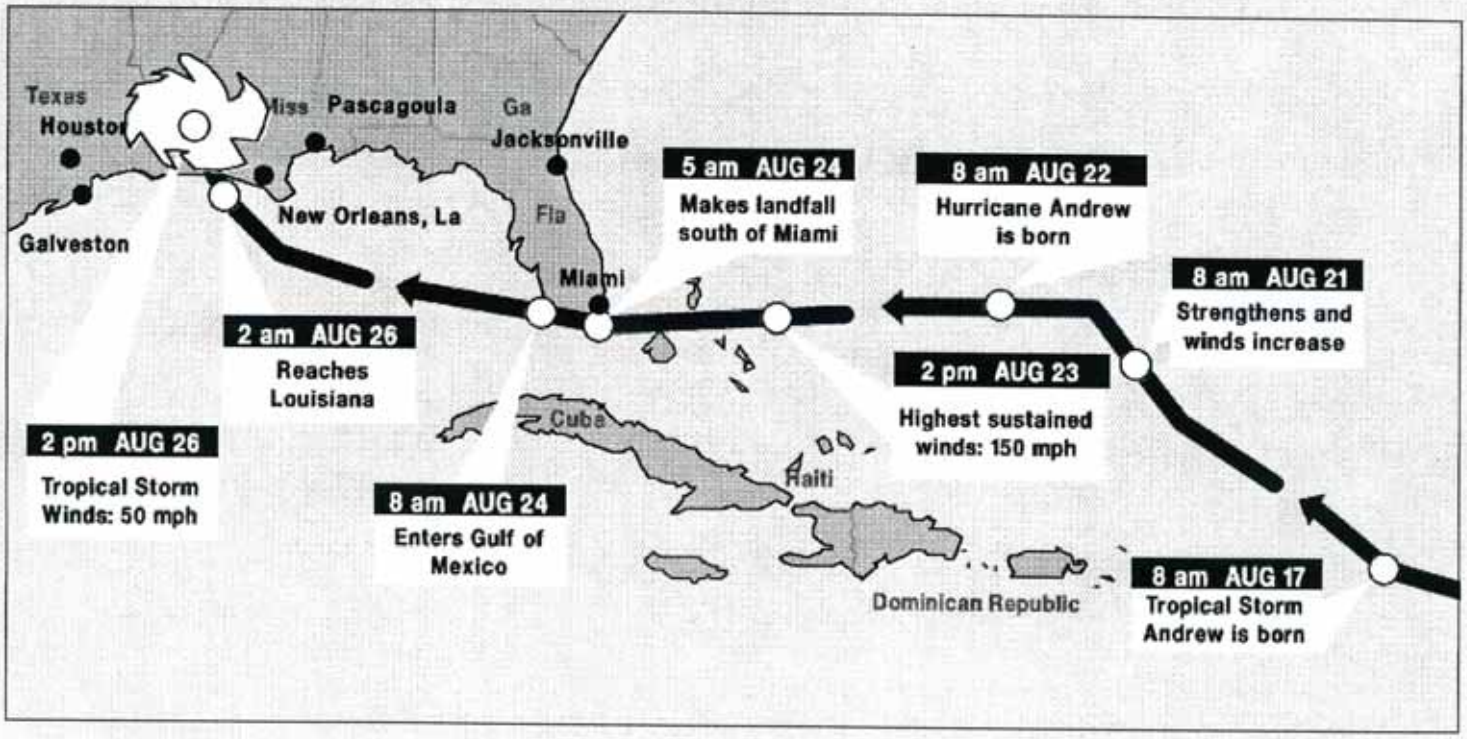
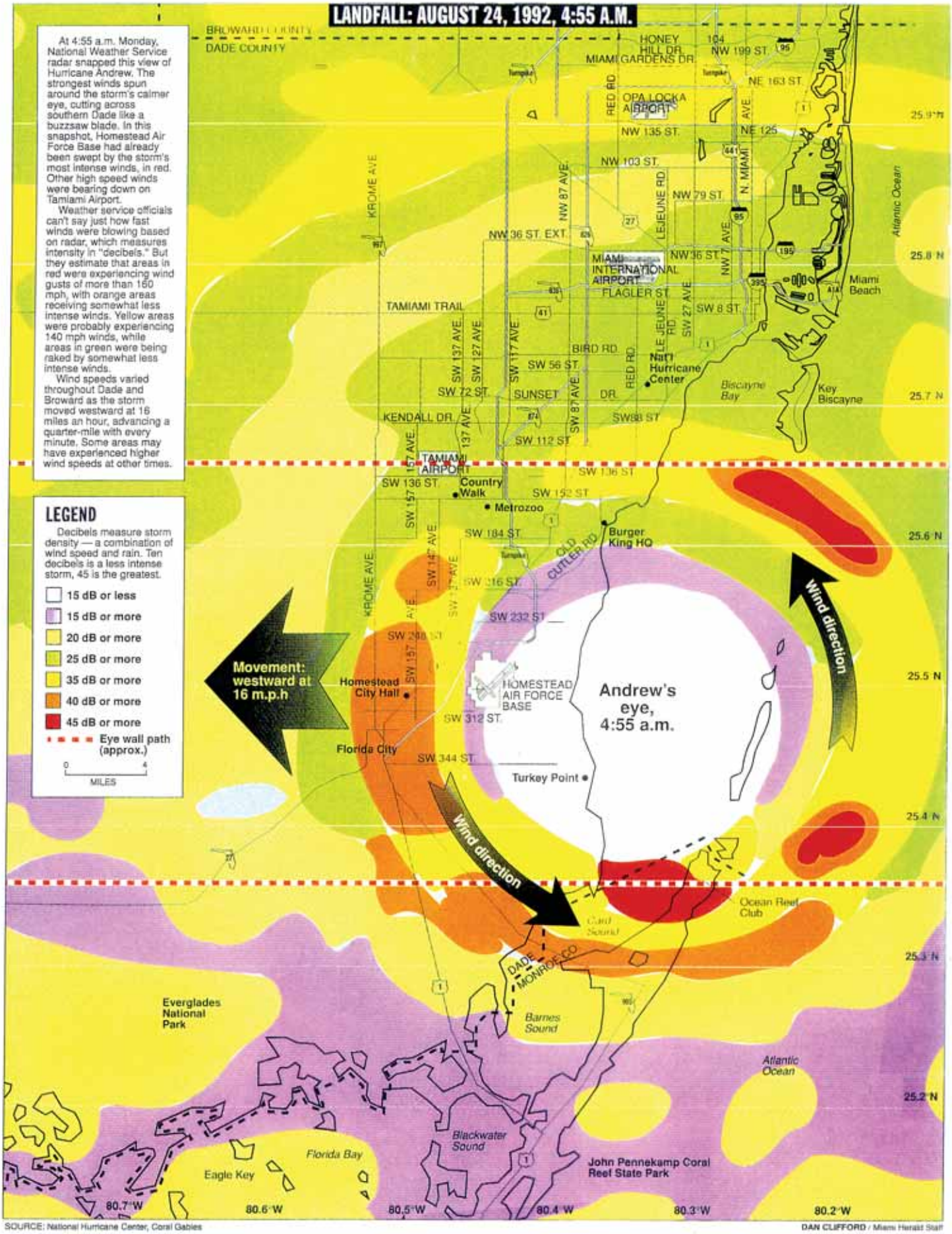


FIGURE 4

PATH OF HURRICANE ANDREW



Source: Reprinted with permission from the Sun Sentinel, Fort Lauderdale, Florida.



SOURCE: National Hurricane Center, Coral Gables

DAN CLIFFORD / Miami Herald Staff

FIGURE 6

WIND SPEEDS – BROWARD COUNTY

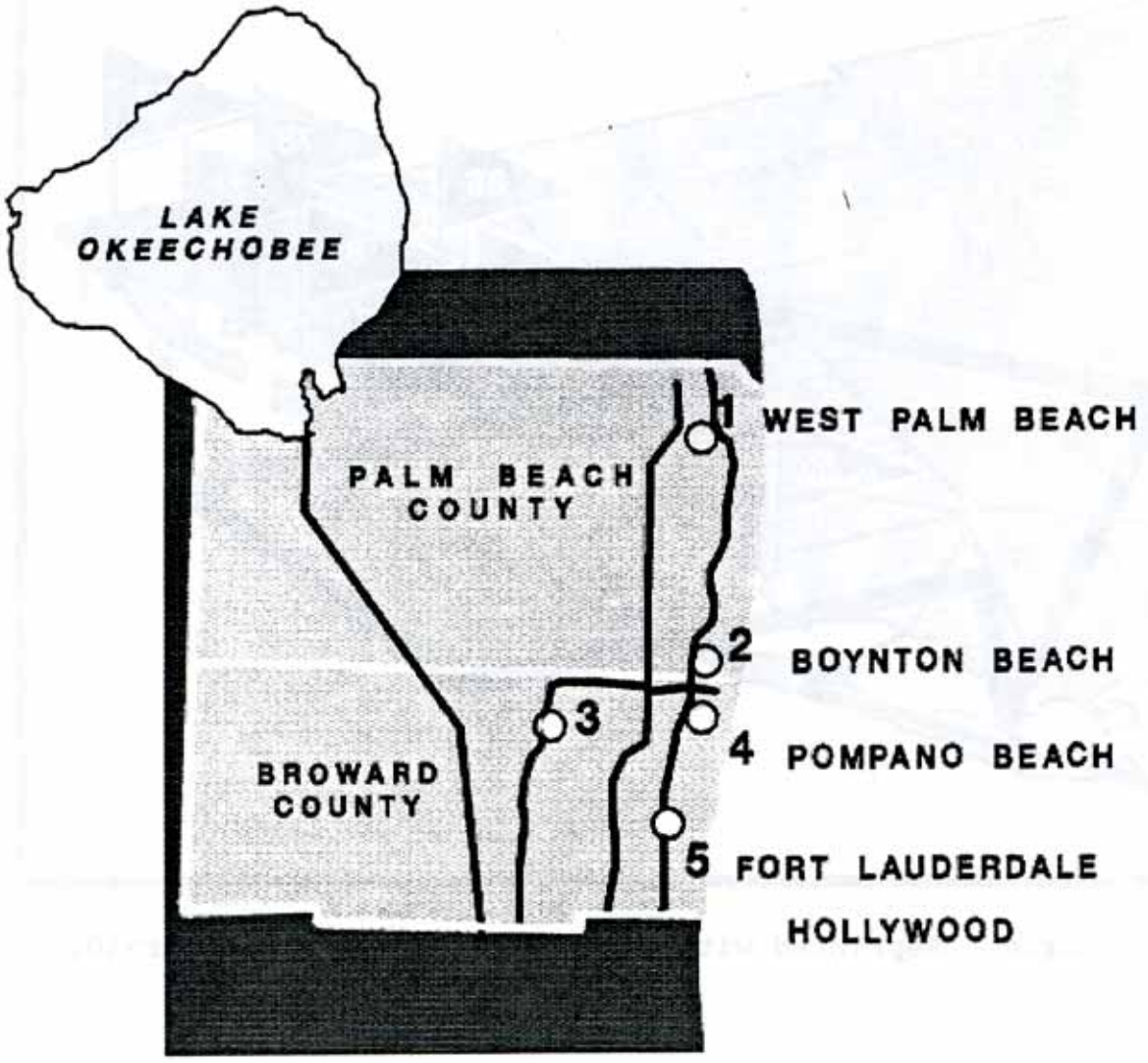
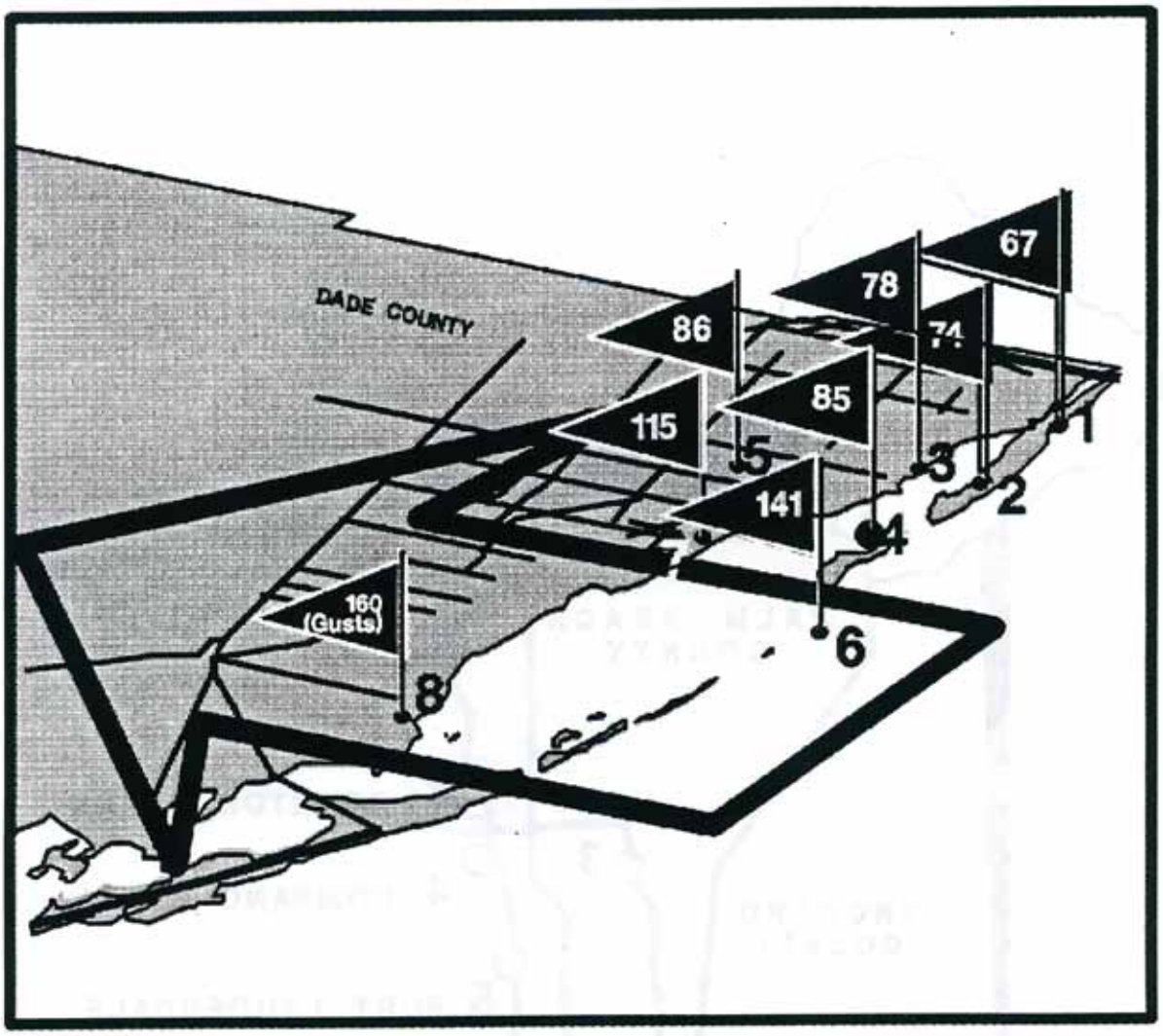


FIG 7

WIND SPEEDS



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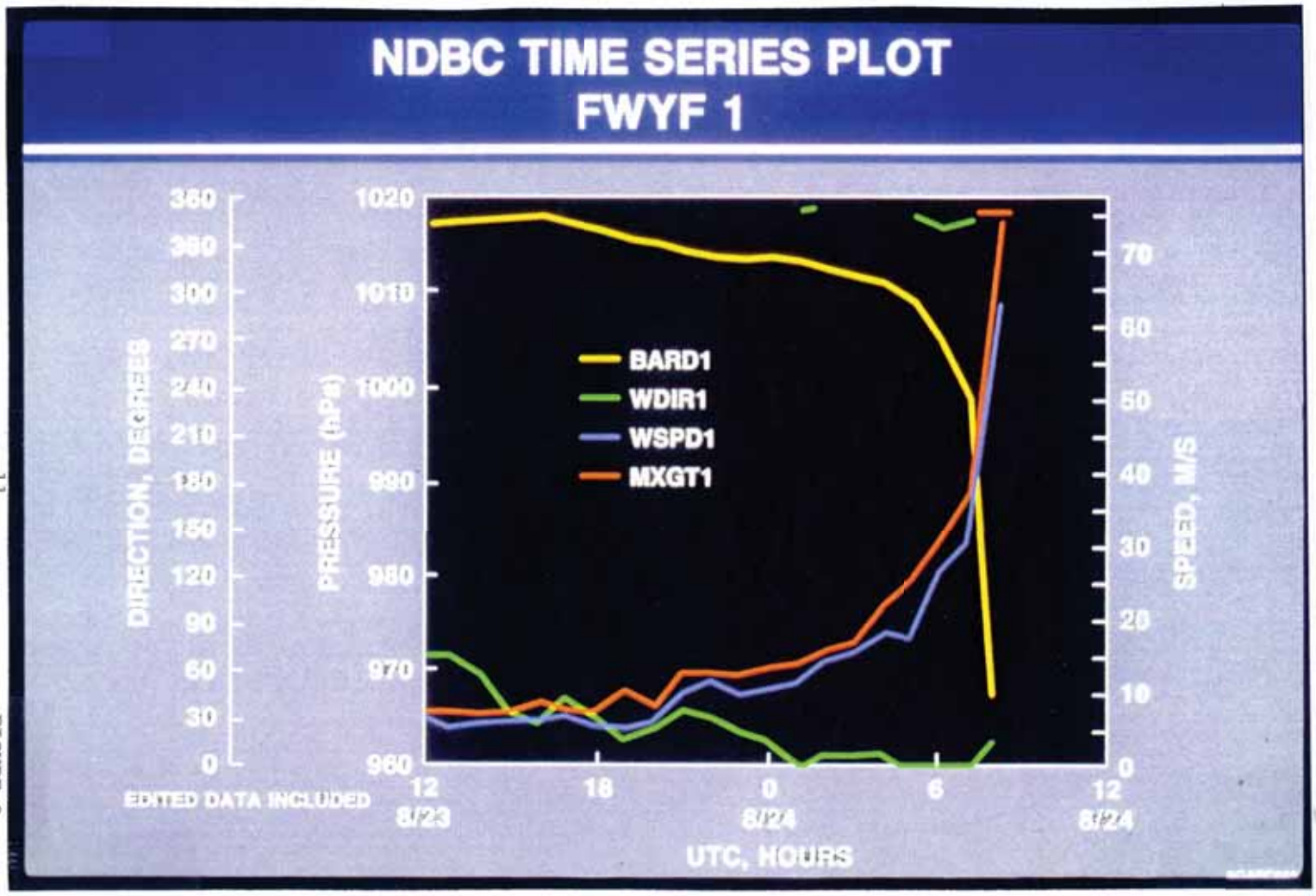

NDBC TIME SERIES PLOT
FWYF 1
DIRECTION, DEGREES
360
330
300
270
240
210
180
150
120
90
60
30
0
PRESSURE (hPa)
1020
1010
1000
990
980
970
960
BARD1
WDIR1
WSPD1
MXGT1
SPEED, M/S
70
60
50
40
30
20
10
0
EDITED DATA INCLUDED
12
8/23
18
0
8/24
6
12
8/24
UTC, HOURS

FIGURE 8

TABLE 3
SURGE LEVELS - DADE COUNTY

Location	Storm Surge (Depth, Feet NGVD)
1. Morningside Ave.	3.7
2. Bayside	5.3
3. Brickell	7.6
4. Mercy Hospital	9.2
5. Dinner Key	8.8
6. Matheson Hammock	9.4
7. Kings Bay	14.5
8. Burger King	16.9
9. Charles Deering	16.6
10. Saga Bay	10.1
11. Black Point	11.8
12. C-102 Canal	8.8
13. Homestead AFB Canal	8.5
14. Homestead Bayfront Park	6.7
15. Bakers Haulover	6.1
16. Key Biscayne (south end)	9.9
17. Key Biscayne (north end)	8.8
18. Elliott Key	9.2

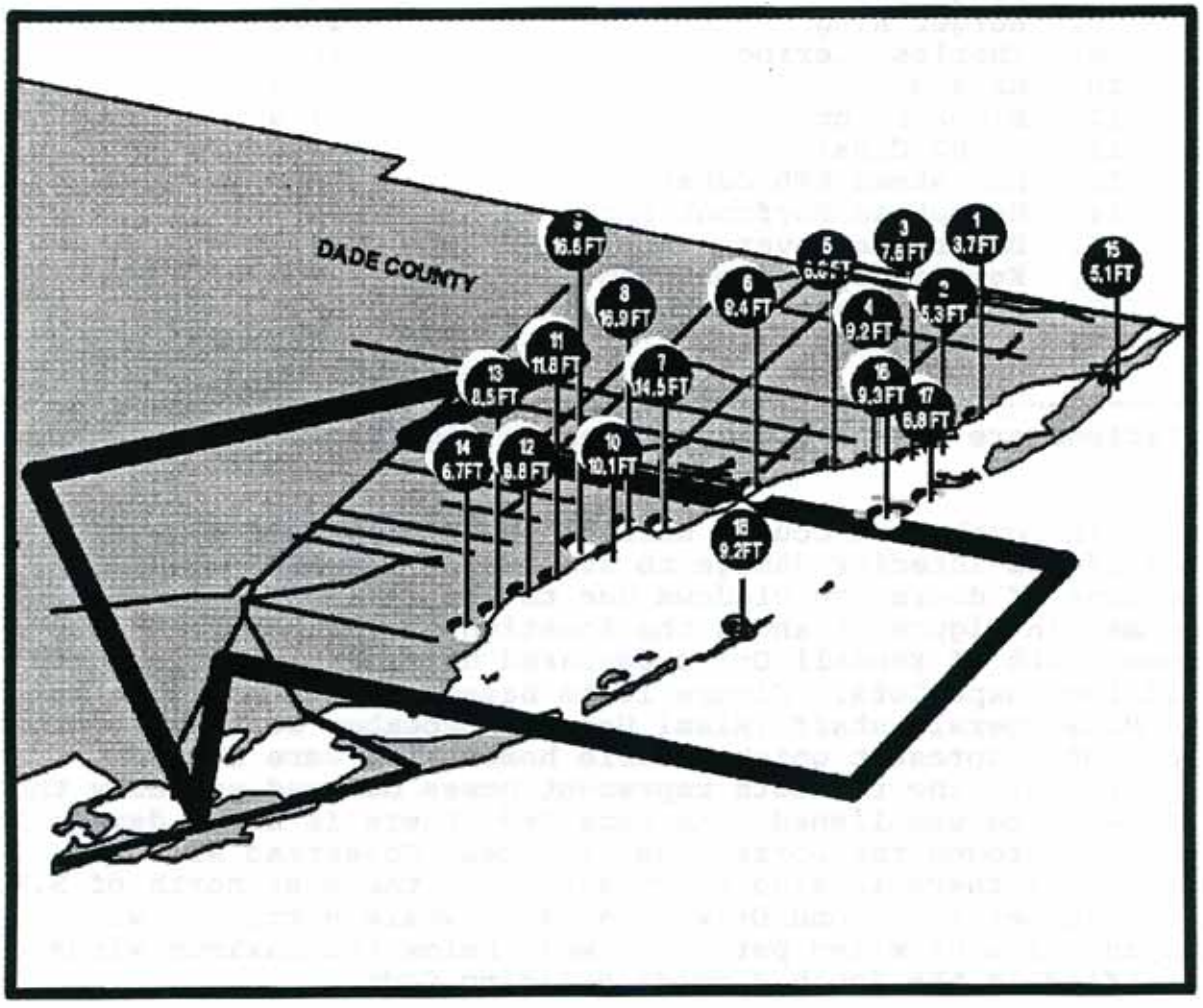
Locations are identified by number in Figure 9.

homes in South Dade County suffered hurricane roof damage. Much of the interior damage to structures was also caused by the loss of doors and windows due to the intense wind pressure. The map in Figure 15 shows the location of the nearly 15,000 homes south of Kendall Drive declared uninhabitable by county building inspectors. Figure 15 is based on data analyzed by the Miami Herald staff (Miami Herald, December 20, 1992). The blue dots represent uninhabitable homes that were deemed repairable. The red dots represent homes damaged so badly that they will be demolished. As expected, there is heavy damage in the area around the worst wind zone near Homestead Airforce Base. But there is also heavy damage in the zone north of S.W. 168th Street (Richmond Drive), an area where hurricane winds stayed below 96 miles per hour, well below the maximum winds specified in the South Florida Building Code.

8. The county has estimated that over 7,800 businesses and 120,000 jobs were lost. An estimated $1.04 billion was lost to agriculture. Over $7.3 billion in insurance claims are expected. Of the estimated 2,100 small businesses in south Dade County, 90 percent were totally destroyed. The Cutler Ridge Mall and nearby Homestead Air force Base were totally

FIGURE 9

STORM SURGE DEPTHS



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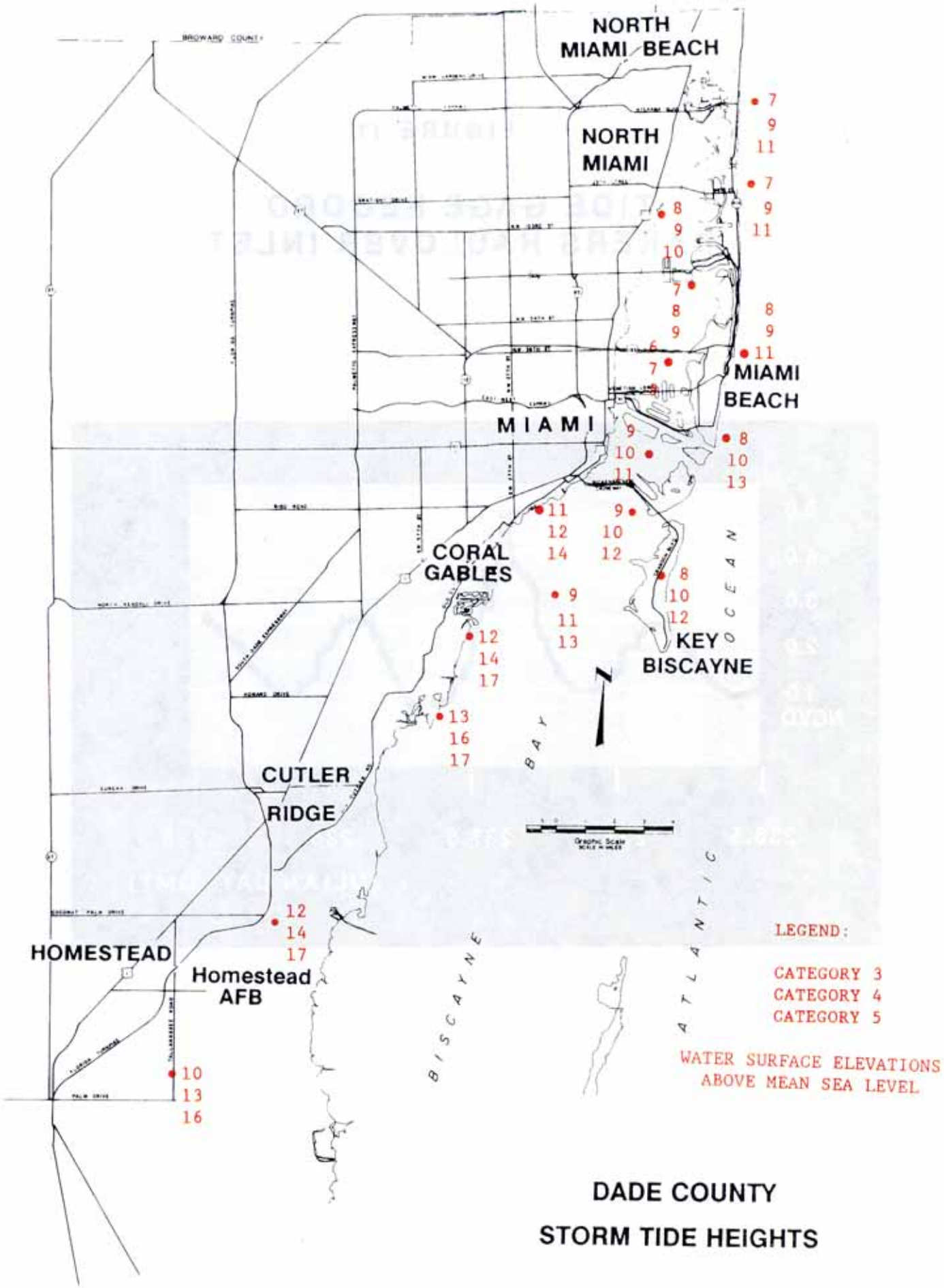


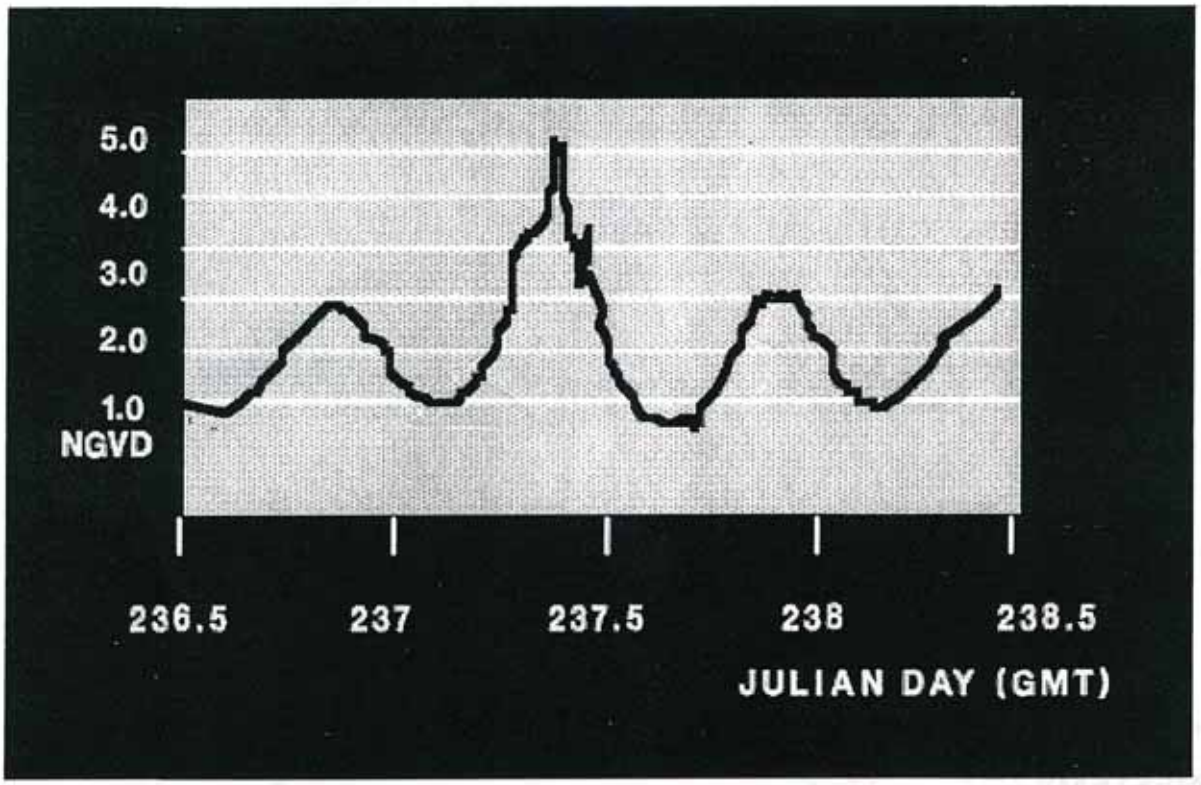
DADE COUNTY

STORM TIDE HEIGHTS

FIGURE 10

FIGURE 11

TIDE GAGE RECORD
BAKERS HAULOVER INLET



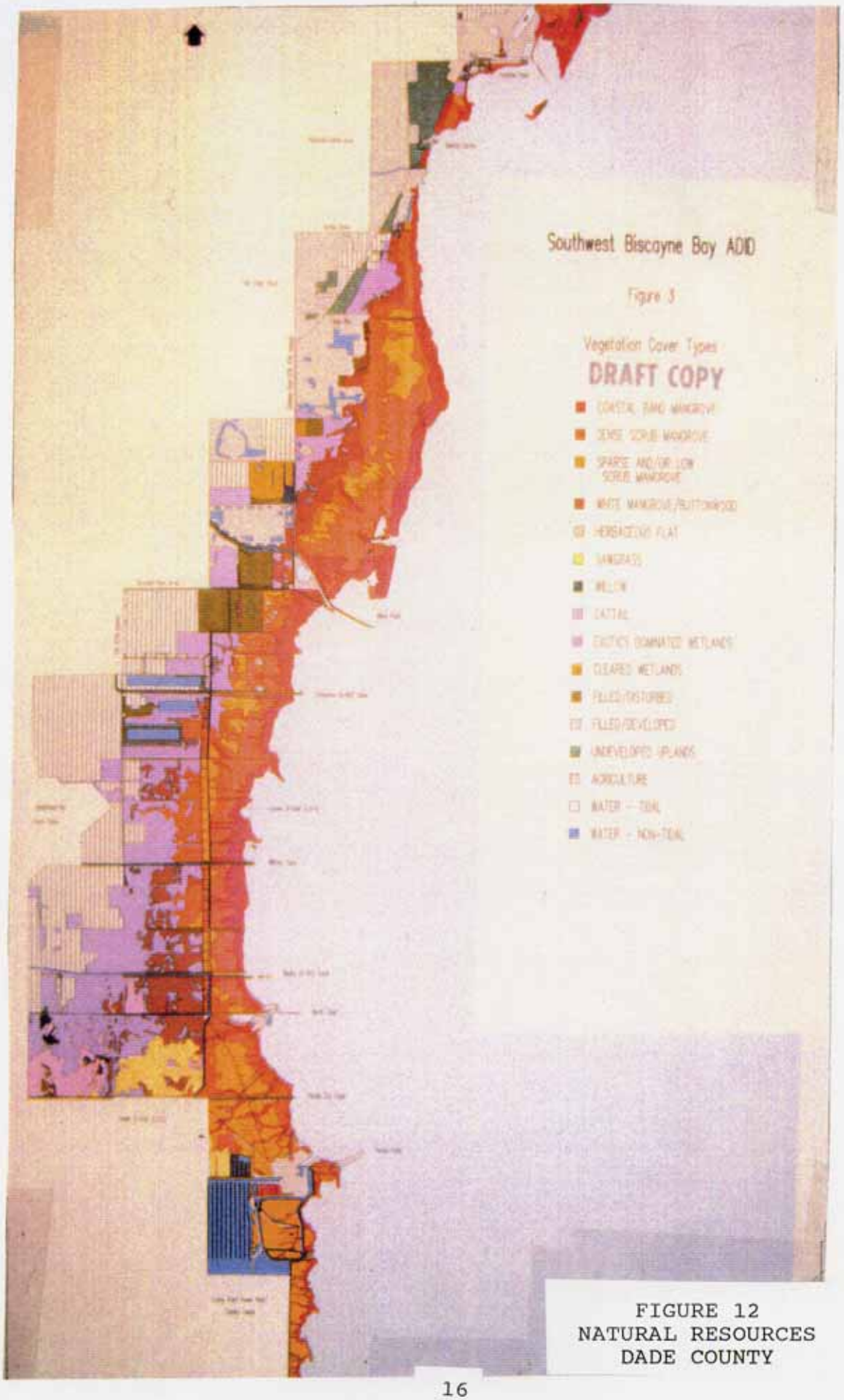


FIGURE 12
NATURAL RESOURCES
DADE COUNTY

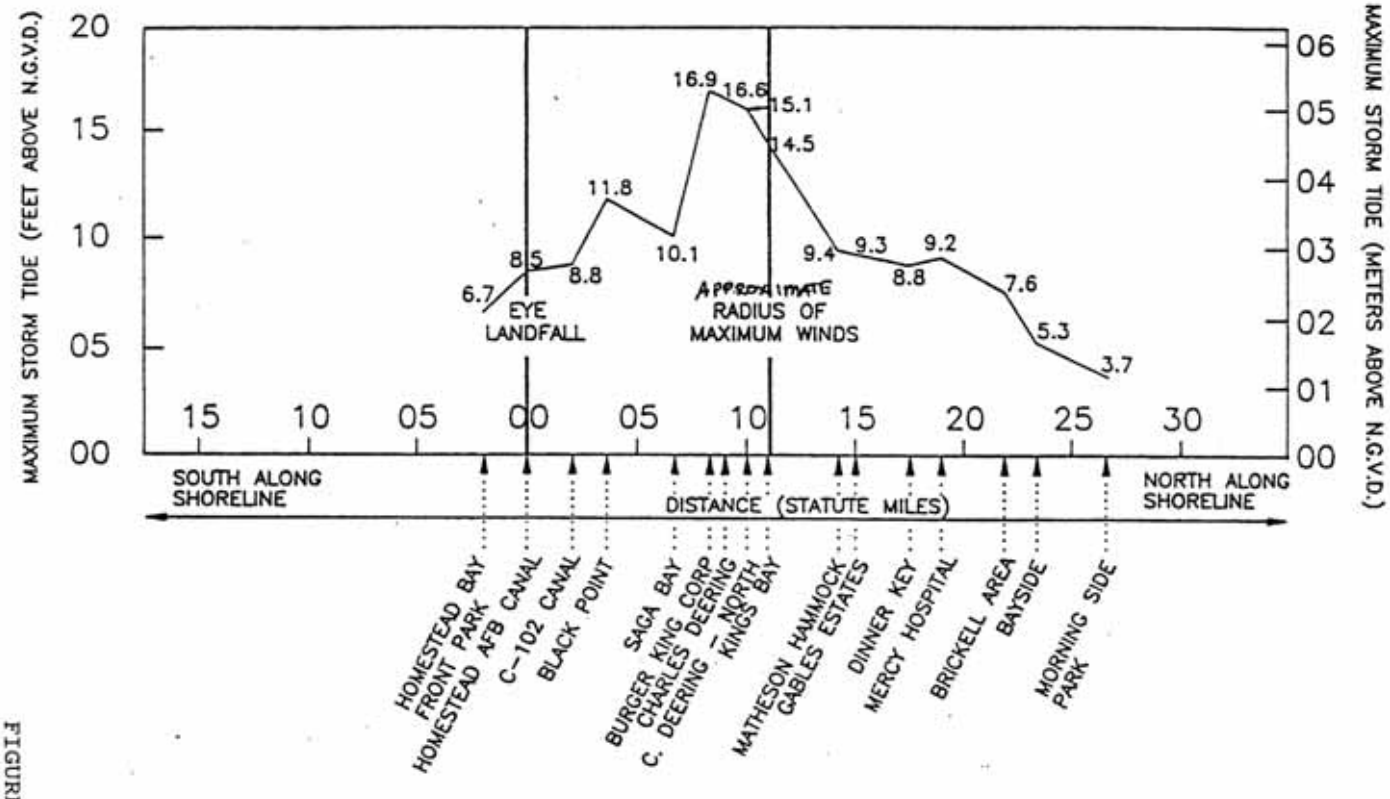


FIGURE 13

Plot of preliminary storm tide heights along western shore of Biscayne Bay, Florida associated with Hurricane Andrew on 24 August 1992. Heights are in feet above NGVD. (Provided by the U.S. Geological Service under a mission assignment from FEMA.)

FIGURE 14
PRESSURE ZONES, WIND ZONES AND STORM SURGE CONTOUR

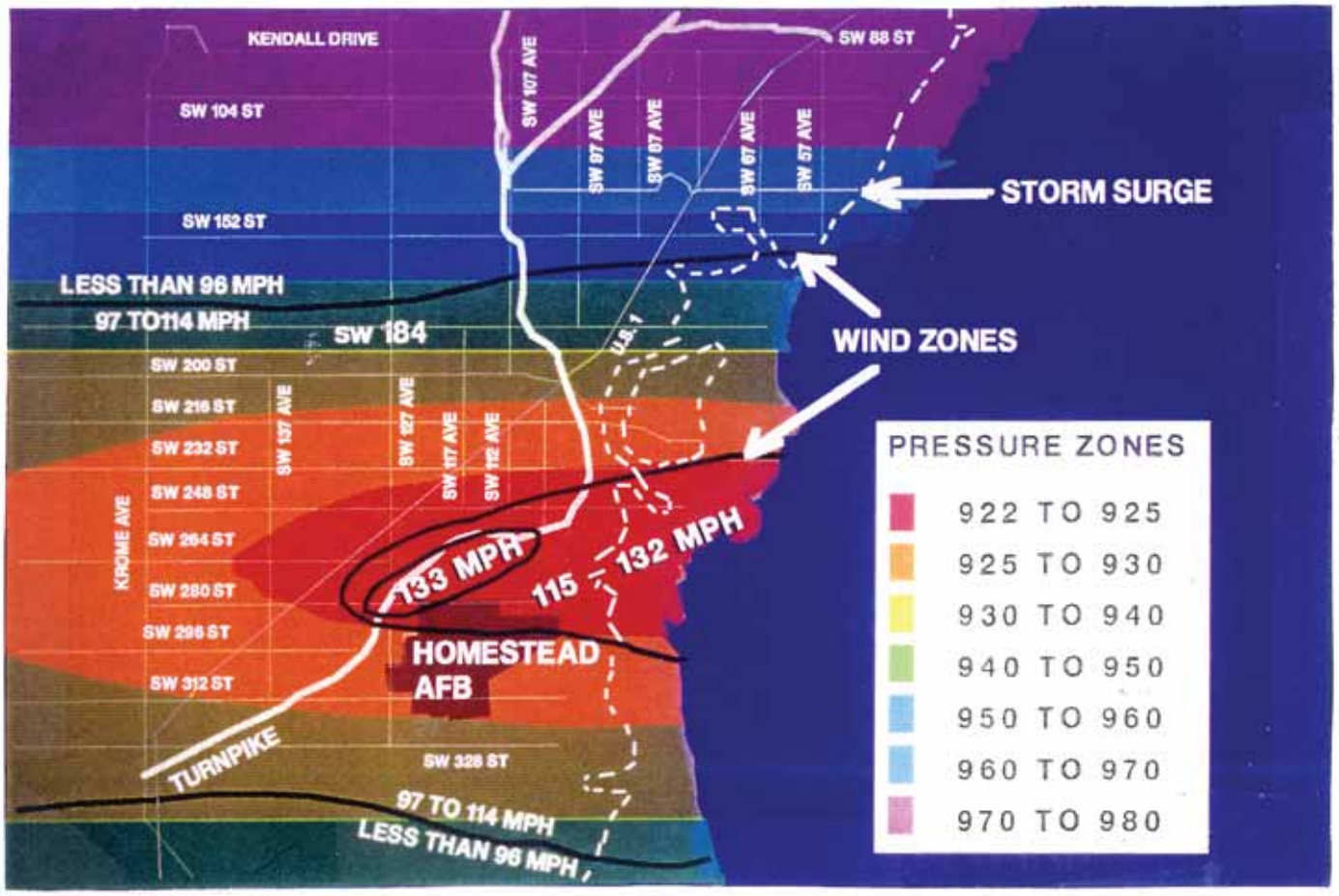


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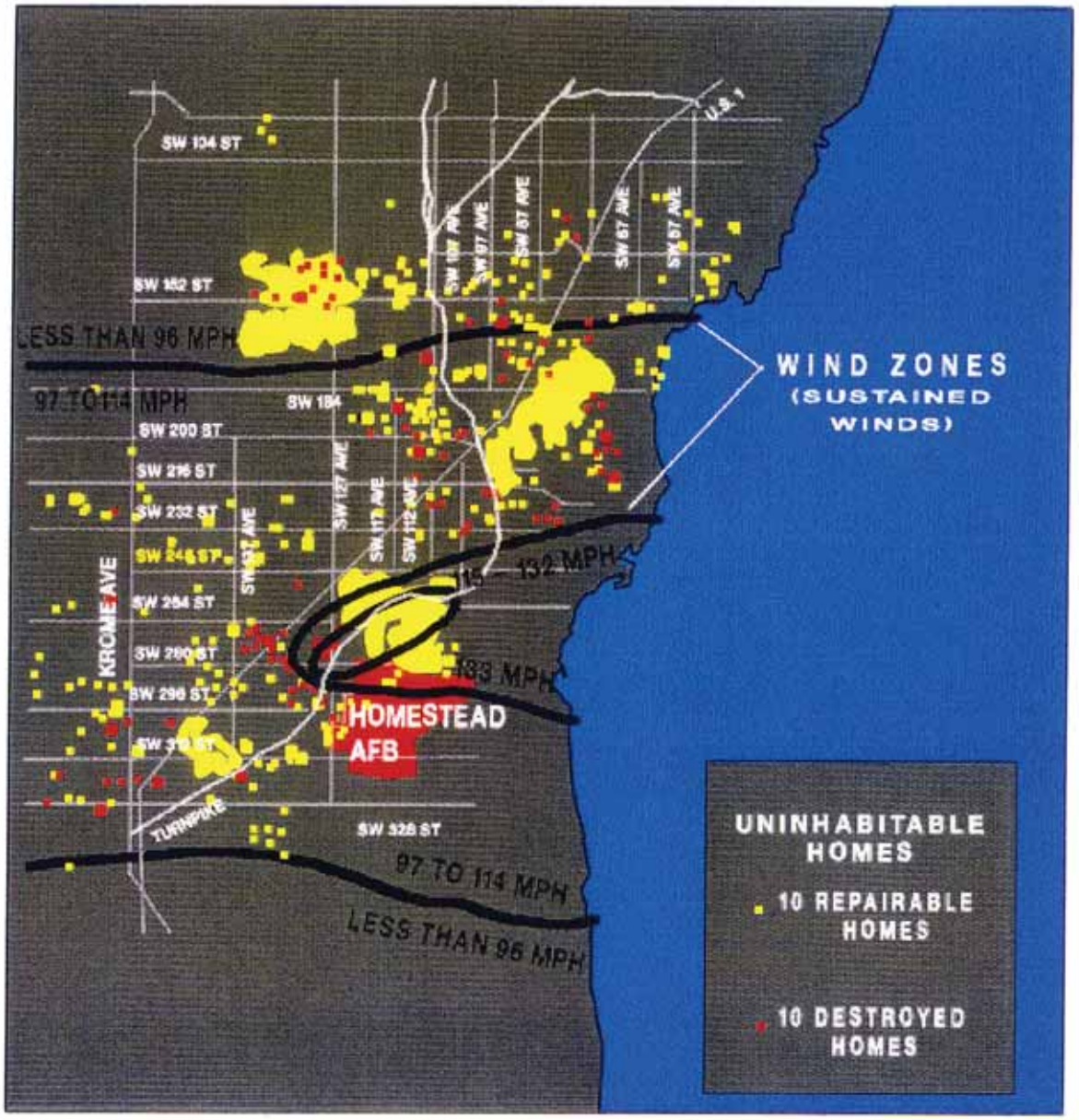
FIGURE 15

LOCATION OF UNINHABITABLE HOMES



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destroyed. The storm did $100 million in damages to the Florida Power and Light nuclear power plant at Turkey Point. Cleanup costs are estimated at $10.0 billion.

9. Dade County estimates that 80 to 90 percent of the coastal mangrove fringe within the 20 mile storm band depicted in Figure 11 was lost. This is roughly equivalent to 10,112 acres of mangroves. About 67 acres of herbaceous brackish march flats and 801 acres of native dominated freshwater wetlands were destroyed. About 2,966 acres of wetlands dominated by exotic species were destroyed.

10. The county has documented impacts to over 50 percent of the artificial reefs. These impacts are listed in Table 4. Slight to moderate impacts were noted to the near shore reef system. Moderate impacts were found to offshore reef areas at the 65-75 foot depth. Slight to moderate impacts were found in reef areas at the 45-55 foot depth. Slight impacts were found to reef areas in less than 40 feet, with exceptions. Figures 16 through 19 depict damages to mobile homes, town homes, duplexes, and single family homes, respectively.

TABLE 4
HURRICANE ANDREW IMPACTS
DADE COUNTY ARTIFICIAL REEFS

REEF	DEPTH LENGTH & MATERIAL	LOCATION	DAMAGE
Almirante	125'/200'+ steel ship	South Dade	Turned upside down
Andro	103'/165' steel freight	North Dade	Ripped and twisted deck
Arida	88'/165' steel freighter	Key Biscayane	Flattened and Crushed
Belcher Barge	58'/195' steel barge	Key Biscayane	No damage
Belzona Barge	58'/215' steel barge	Key Biscayane	Moved West 0.5 mile
Belzona Two	60'/90' steel tug	Key Biscayane	Moved 100', lost wheelhouse
Biscayne	55'/120' steel freighter	Key Biscayane	Damaged by Miracle Express
Blue Fire	110'/175' steel freighter	South Dade	Collapsed, bottom ripped off
C-One	68'/120' steel tug	North Dade	No damage
Conception	68'/150' steel freighter	North Dade	Broken into three pieces
Doc DeMily	140'/287' steel freighter	South Dade	No damage
Lakeland	130'/200' steel freighter	Key Biscayane	Collapsed
Miracle Express	55'/100' steel ship	Key Biscayane	Destroyed, moved, damaged Biscayne
Miss Karline	51'/81' steel ship	Miami Beach	Broken into pieces
Proteus	72'/220' steel freighter	Key Biscayane	Moved and broken into pieces

Information in Table 4 provided by Dade County.

TABLE 5
COSTLIEST STORMS (U.S.)

RANK BY DOLLARS	NAME	YEAR	DOLLARS DAMAGE
1.	ANDREW	1992	$20.0 BILLION
2.	HUGO	1989	$ 7.0 BILLION
3.	BETSY	1965	$ 6.3 BILLION
4.	AGNES	1972	$ 6.3 BILLION
5.	CAMILLE	1969	$ 5.1 BILLION

COMPARISONS TO OTHER STORMS

11. Only two other storms this century were more intense. The first and worst was the unnamed Labor Day Hurricane that hit and killed 408 people. Its central pressure was 26.35 inches. The second was Hurricane Camille, which hit the Louisiana and Mississippi coasts and killed 256. Hurricane Camille's central pressure was 26.84 inches. Hurricane Andrew by far ranks as the costliest hurricane to date, with almost three times the damages as Hurricane Hugo. The costliest storms to date in the U.S. are shown in Table 5.

12. In Florida, only the Labor Day 1935 hurricane was more powerful than Hurricane Andrew. Other category four storms affecting Florida are shown in the Table 6 and in Figure 20.

TABLE 6
MOST INTENSE FLORIDA HURRICANES

RANK BY INTENSITY	NAME	YEAR	CATEGORY	BAROMETRIC PRESSURE	U.S. DEATHS	DEATH TOLL RANK
1	Labor Day Hurricane	1935	5	26.35	408	5th
2	Andrew	1992	4	27.34	48	23rd
3	Unnamed	1919	4	27.37	600-900	3rd
4	Unnamed	1928	4	27.43	1836	2nd
5	Donna	1960	4	27.46	48	21st

Category 4 Sustained winds 131-155 miles per hour.
Category 5 Sustained winds over 155 miles per hour.

FIGURE 16
DAMAGE TO MOBILE HOMES

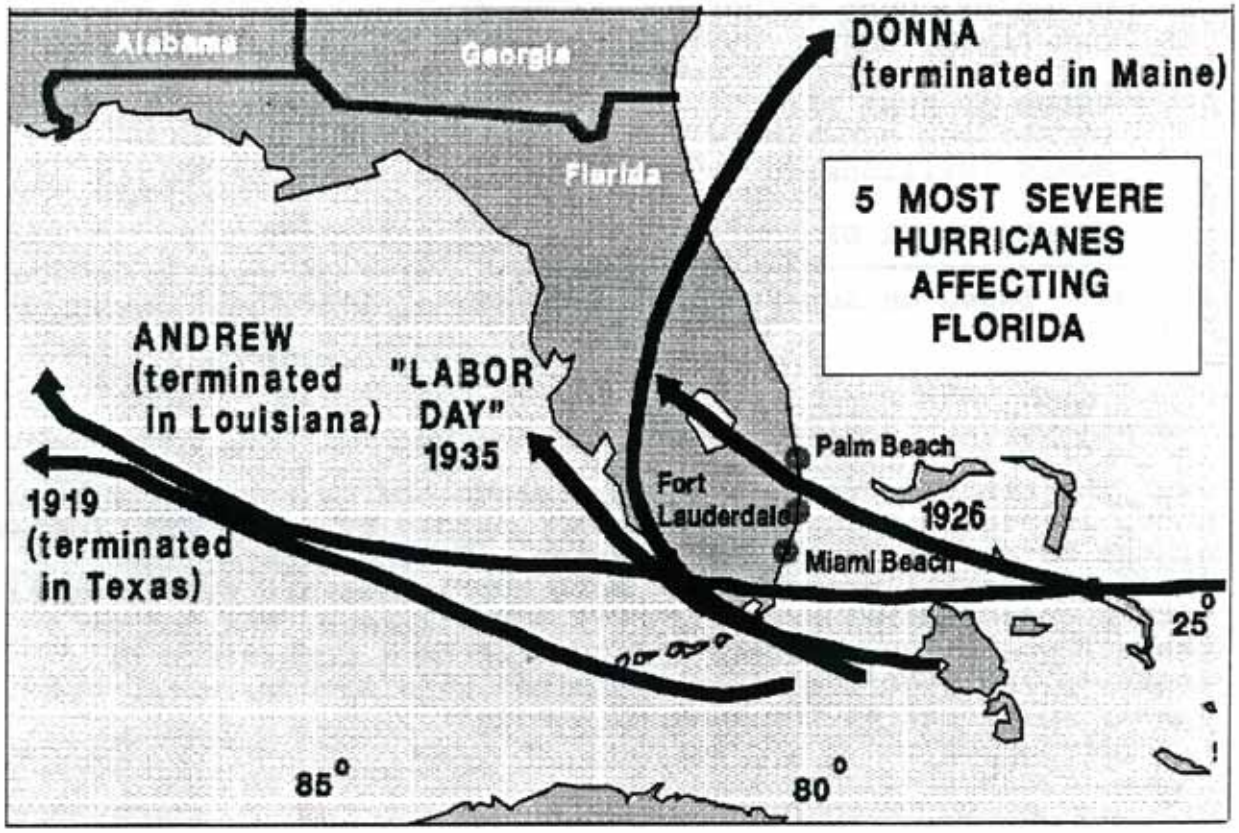
FIGURE 17
DAMAGE TO TOWN HOMES

FIGURE 18
DAMAGE TO DUPLEX

FIGURE 19
DAMAGE TO SINGLE FAMILY HOMES

FIGURE 20

STORM TRACKS
FIVE WORST FLORIDA STORMS



13. It's hard to believe, but in a way south Florida was very lucky. Destruction would have been much worse if Andrew had come ashore further to the north. (Source - Sun-Sentinel, August 1992). Damages for the Fort Lauderdale area have the potential to be three times that of those actually experienced in South Dade.

TABLE 7
DAMAGE POTENTIAL

WHAT IF ANDREW HIT ::::::::::::	FORT LAUDERDALE	BOCA RATON	SOUTH DADE
PEOPLE AT RISK	614,558	320,861	202,036
VALUE OF OWNER OCCUPIED ONE-FAMILY HOMES (Billions)	$12.60	$10.23	$3.10
VALUE OF RENT PAID, EXCEPT FOR ONE-FAMILY HOMES (Millions)	$42.50	$21.50	$8.30
TOTAL NUMBER OF HOMES	302,003	179,304	71,436

Source: Based on Sun-Sentinel analysis of 1990 U.S. Census Data.

COMPARISONS TO HURRICANE HUGO

14. The central pressure of Hurricanes Andrew and Hugo are shown in Figure 21. The data was provided by Dr. Andrew Garcia of the Waterways Experiment Station. In the figure, the landfall central pressures of both hurricanes are nearly equal with Hugo's central pressure near 930 milibars, and Andrew's pressure near 920 milibars. Figure 22 is a comparison of Andrew's and Hugo's maximum sustained wind speeds, which are nearly identical at the time of landfall.

FIGURE 21

CENTRAL PRESSURE OF HURRICANES ANDREW AND HUGO TIME RELATIVE TO U. S. MAINLAND LANDFALL

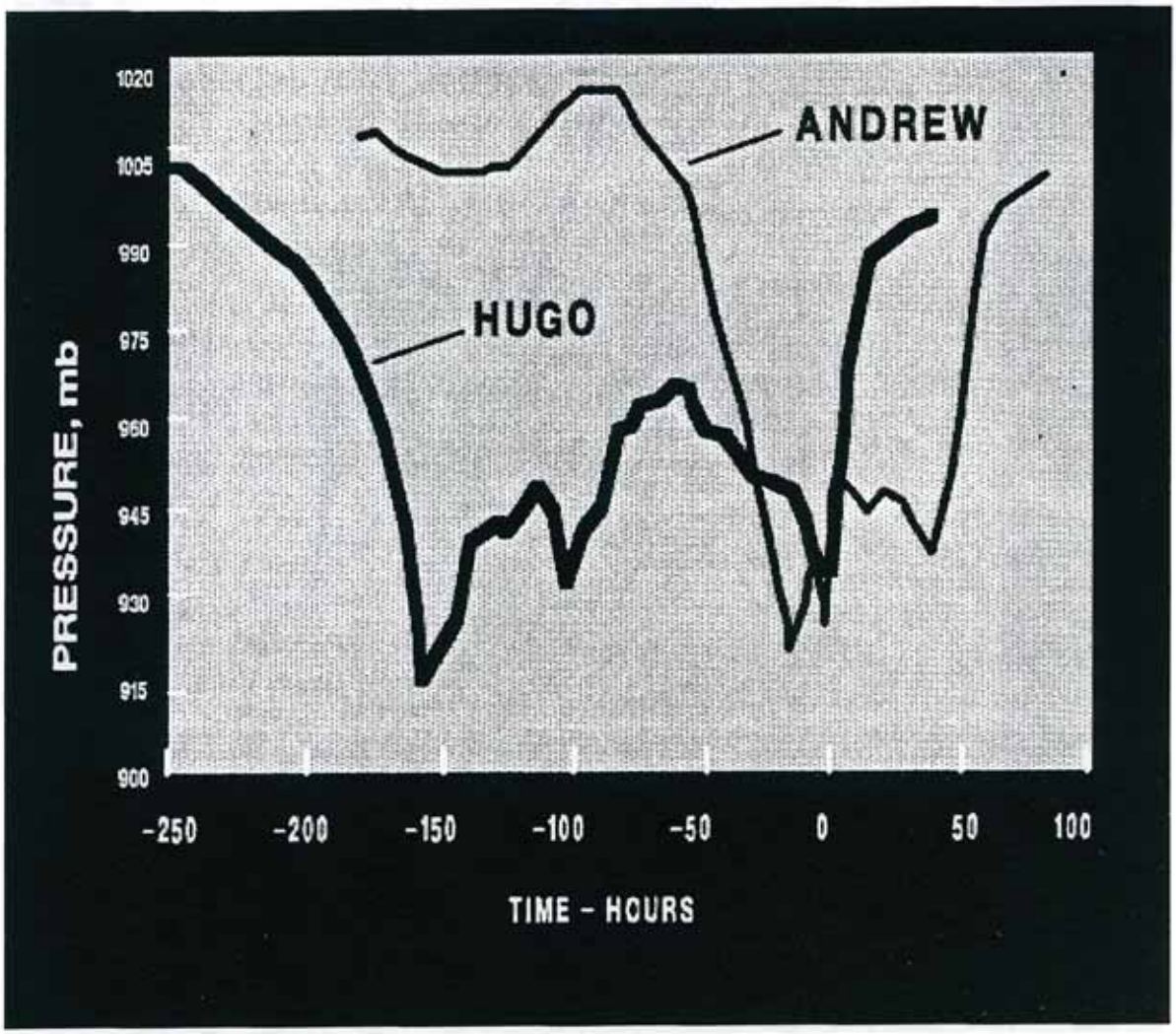
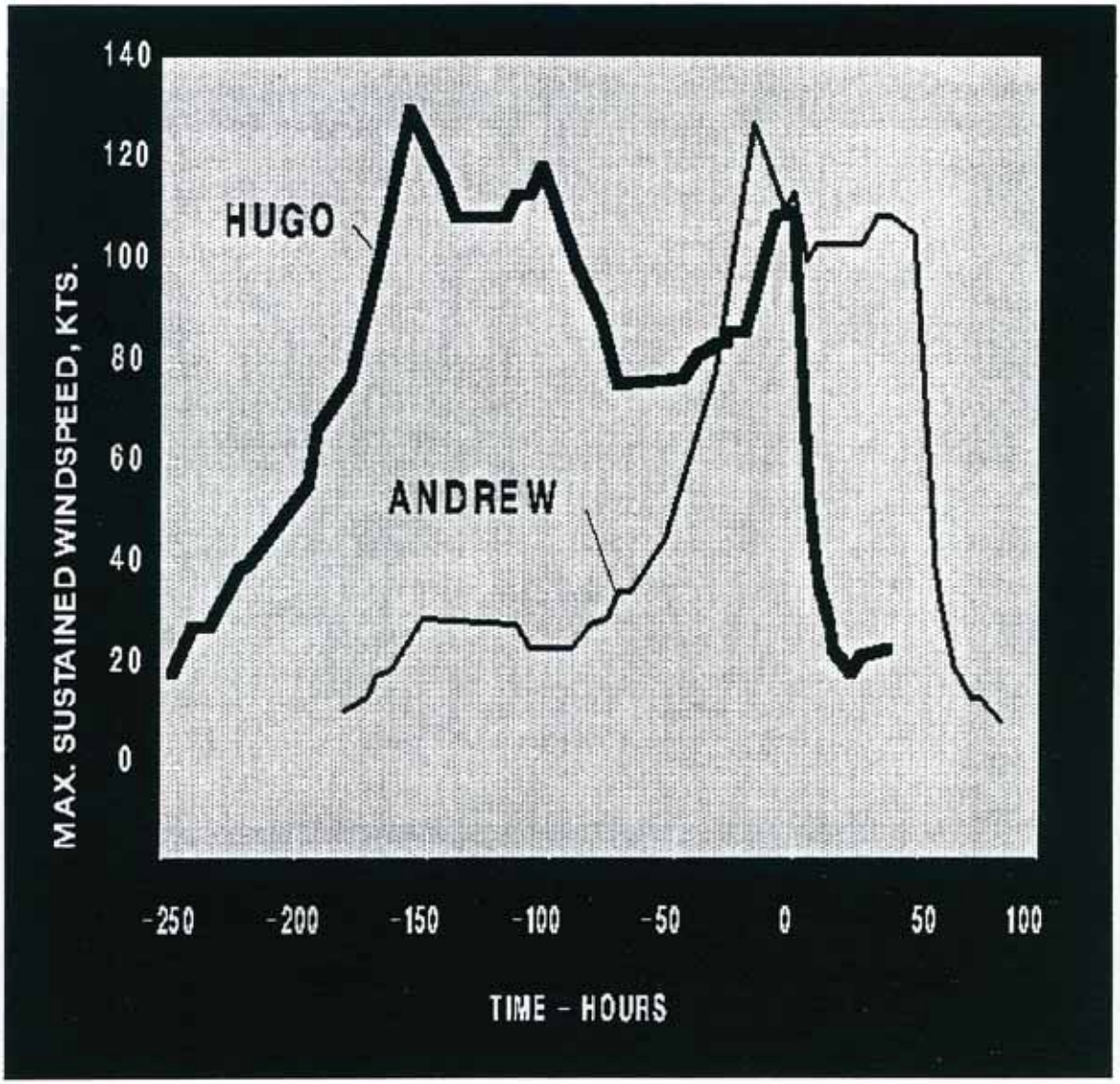


FIGURE 22

MAXIMUM SUSTAINED WIND SPEEDS
HURRICANES ANDREW AND HUGO
TIME RELATIVE TO U. S. MAINLAND LANDFALL



U.S. ARMY CORPS OF ENGINEERS EMERGENCY MISSIONS

15. At 6:00 p.m. on August 24, Air Force One touches down at Opa-locka Airport. President Bush and Florida Governor Chiles visit the devastated areas. Dade County, Broward County, and portions of Monroe and Collier Counties were declared Federal disaster areas by the President.

16. The Jacksonville District is actively supporting the Hurricane Andrew Federal response and recovery effort in South Florida. To date there have been 14 missions assigned to the U.S. Army Corps of Engineers by the Federal Emergency Management Agency (FEMA) totaling $536,500,000. Over 17,000 contractor personnel were working on Corps contracts. As of October 6, 1992, there were 617 USACE employees in the Hurricane Andrew Recovery Office (HARO) in Miami area, supported by 6 people in the Emergency Operations Center (EOC) in the Jacksonville District office, and an additional 48 people full time in the Jacksonville District. As of October 26, 1992, there were 576 USACE employees in the HARO/Miami area. The Red Cross has spent over $26.3 million helping 33,835 families. The following are brief summaries of the missions assigned to the Corps (status - 31 DEC 92):

17. Plastic Roofing. (Mission 1, $27.6M) A total of 32.7M square feet of material has been issued. This is enough plastic to cover 21,794 homes. The work was essential completed 28 November 1992.

18. Debris Removal. (Mission 2, $375M) This is by far the largest FEMA mission assigned to the Corps. It represents 60 percent of the missions assigned in terms of funds. Six contractors are continuing work. Dade County is responsible for disposal and disposal management. A total of 12.7 million cubic yards of debris was removed during the debris hauling phase of this FEMA mission (November 1992). Production rates for debris removal were roughly 100,000 truck loads per day. One hundred thousand cubic yards of debris would cover a football field 100 yards long by 50 yards wide to a depth of 60 feet. 3.7 million cubic yards is roughly equivalent to 148,000 truck loads, or a convoy 700 miles long (Miami to Atlanta). To remove all the debris would fill a convoy bumper to bumper from Miami to Seattle and back again. Figure 23 and 24 depict debris and debris removal operations.

19. Construction and demolition material is estimated at 1.3 million cubic yards of debris, equivalent to 13 Nimitz class aircraft carriers. A total of 39 burn sites have been approved by Dade County. Figure 25 shows a typical burn site. HARO had responsibility for removal of sunken vessels in and around four marinas. The debris removal work is continuing, with an estimated completion date of November 1993.

FIGURE 23
DEBRIS

FIGURE 24
DEBRIS REMOVAL

FIGURE 25
DEBRIS BURN SITE

21. Emergency Pumps and Generators. (Mission 3, $10M) 163 generators have been issued, with 138 on hand.

22. Potable Water. (Mission 4, $4.5M) Total deliveries to date for both tanked and bottled water is 1,374,051 gallons, about 5,723 tons. This mission has been completed.

23. Public Affairs Officer. (Mission 5, $40K) The mission has been completed.

24. Technical Assistance. (Mission 6, $1M) School structural assessments have been finished, and the mission is completed.

25. Portable Toilets. (Mission 7, $6M) A total of 3,068 have been installed, not including 380 placed by others.

26. Ice. (Mission 8, $6M) At one point, the FEMA mission allocation was for 540,000 pounds per day. This is equivalent to a cooler of ice per day for 20,000 people, or enough to supply 9 Orange Bowl games per day. The contract has been completed.

27. Damage Survey Reports. (Mission 9, $1.3M) Over 800 Damage Survey Reports have been submitted to FEMA to date. This work is continuing.

28. Schools. (Mission 10, $60M) Estimate and repair damages to 65 schools assigned to the Corps. About 55 schools were repaired and opened on schedule. The Corps is acquiring 600 modular classrooms to alleviate overcrowding. The Dade County public school system is the nation's fourth largest, with 278 schools. This mission is scheduled for completion in June 1993.

29. Garbage. (Mission 11, $10M) Provide for the collection and disposal of garbage during the response phase of the disaster.

30. Showers. (Mission 12, $10M) Provide all showers required during the response phase. Current requirement remains at 301 heads.

31. Assessment of Hurricane Evacuation Procedures. (Mission 13, $50K). Mission completed.

32. Temporary Housing. (Mission 14, $23.4M) Design and develop travel trailer/mobile home parks, clear and prepare pads.

IMPACTS TO THE BEACHES OF SOUTH FLORIDA

SUMMARY OF DISTRICT BEACH INVESTIGATIONS

33. The feasibility phase of the Coast of Florida (COF) study is underway for Dade, Broward and Palm Beach counties (Region III). The feasibility cost sharing agreement calls for post-storm monitoring of the beaches in Region III following significant storms. As part of the storm monitoring effort, black and white 8-bit digital aerial images of the coastlines of Dade, Broward and Palm Beach counties were flown on 29-30 August 1992. Additional data collection efforts funded by the COF study were accomplished by the Florida Department of Natural Resources (DNR) and the Coastal Engineering Research Center (CERC).

34. The Jacksonville District performed an aerial inspection and video taped the condition of the coastal areas of Florida from Anna Maria Island south to Marco Island on the gulf coast, and from West Palm Beach to Key Biscayne on the east coast on 25 August 1992. On 2 September 1992, ground inspections were made to Dade and Broward Counties of the shore protection projects and the front row of upland development. Portions of the Dade County hurricane and storm damage reduction project, Virginia Key and Key Biscayne were surveyed by District survey crews.

SUMMARY OF DNR INVESTIGATIONS

35. As part of the COF study storm monitoring efforts, DNR performed on-the-ground inspections including video tape for both coasts of Florida on 25 August 1992. DNR survey crews performed surveys of the beaches in Dade and Broward Counties at 1,000 foot intervals from each DNR survey monument. Broward County performed some of the survey work. The surveys extend from behind the dune seaward to wading depth, and include Virginia Key, Key Biscayne and Fisher Island as well as the remaining coastal islands in both Dade and Broward Counties. DNR, also collected controlled aerial photography of Dade and Broward Counties at a scale of 1" = 100 feet. The controlled aerials were flown Monday, 31 August 1992. DNR staff is preparing a summary of their inspections and findings of coastal damage. In particular, DNR is cataloging the damages to upland development by DNR monument. This information will be published in separate report. Therefore, the remainder of this report will concentrate on the impacts to the beaches, and in particular, to the beach projects.

SUMMARY OF CERC INVESTIGATIONS

36. CERC scientists traveled to Dade County to document still water levels (SWL) generated by the hurricane. Elevations of 16.6 feet at the Derring Estate and 16.9 feet at the Burger King headquarters are the highest reported surge elevations. Surge elevations of 9.3 and 8.3 feet at Key Biscayne and 5.1 feet at the tide gage at Bakers Haulover Inlet were recorded. These water mark locations were reported to the DNR survey crews to determine elevation. The data from the surge gage located at Bakers Haulover Inlet, which was operational during the storm, has been retrieved and is shown in Figure 11.

37. The Jacksonville District is not aware of any wave measurements collected during Hurricane Andrew. Therefore, CERC was tasked to perform a wave hindcast of the hurricane for wave conditions in the vicinity of the Dade County hurricane and storm damage reduction project, as well as in Key Biscayne.

38. The wave hindcast study was directed by Dr. John Hubertz of CERC. A separate report detailing the numerical modeling effort will be published by CERC. Preliminary results are summarized as follows. The Wave Information Study (WIS) wave model, WISWAVE 2.0 was used to make the wave hindcast, with wave data results saved every hour at depths of approximately 12 meters. The wind fields for input to WISWAVE were calculated using the hurricane model HURWIND. The level 1 Hurricane Andrew simulation, with a grid spacing of 15 nautical miles, is shown in Figure 26. Output from this grid was then used in the level 2 grid, which had a one nautical mile grid spacing. The level 2 grid is shown in Figure 27. Model points at the onshore locations were selected to coincide with observed wind and surge data.

39. The resultant numerically predicted wind field as the hurricane neared landfall is shown in Figure 28. The numerically predicted surge is shown in Figure 29. A comparison of the numerically predicted wind and storm surge is shown graphically in Figure 30. The final numerical model results for predicted wave heights for the storm are shown in Figure 31. Deepwater wave heights of 13 meters transformed to nearshore wave heights of between two to three meters. A fairly large portion of the western shoreline of Key Biscayne experienced three meter waves.

FIGURE 26

Hurricane Andrew Simulation
Level 1 Grid (15 nm) for WISWAVE

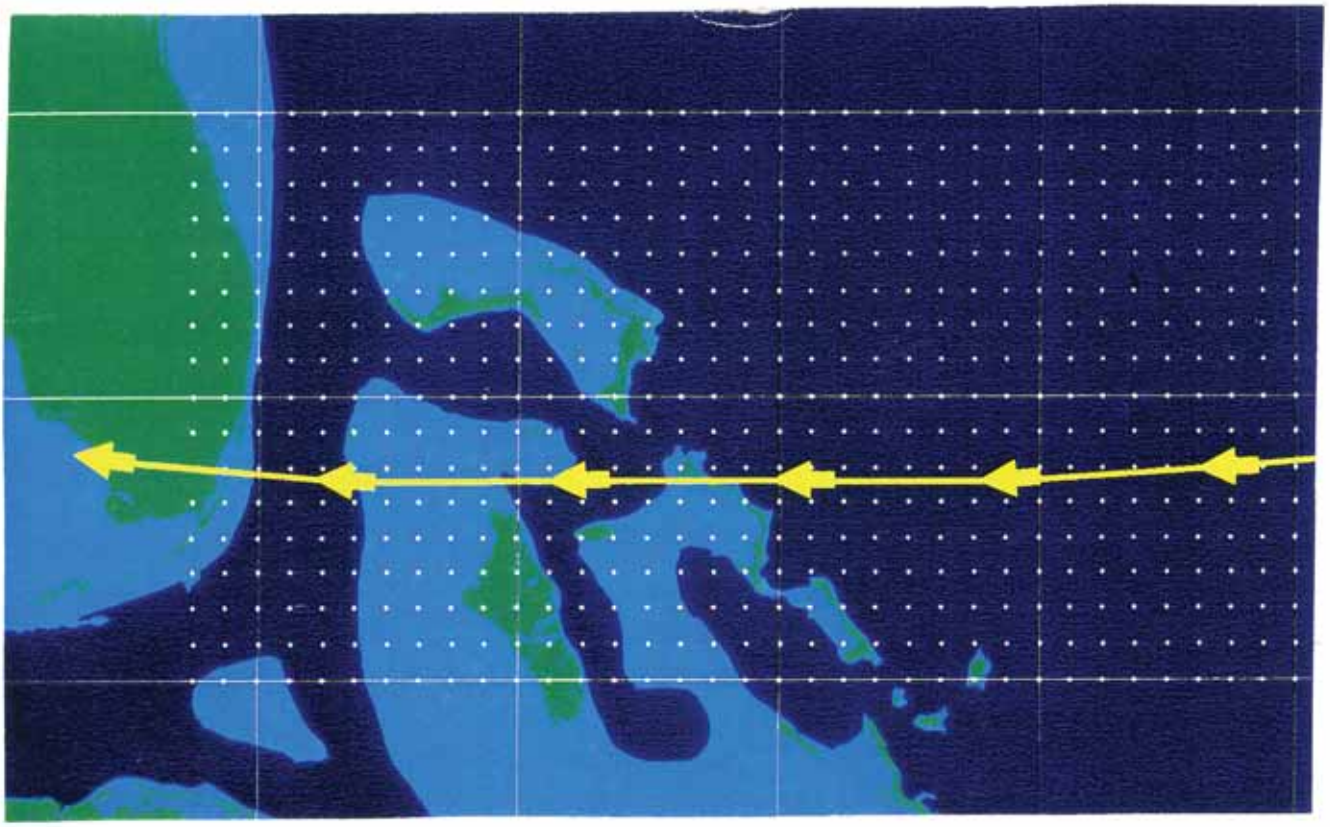


FIGURE 27

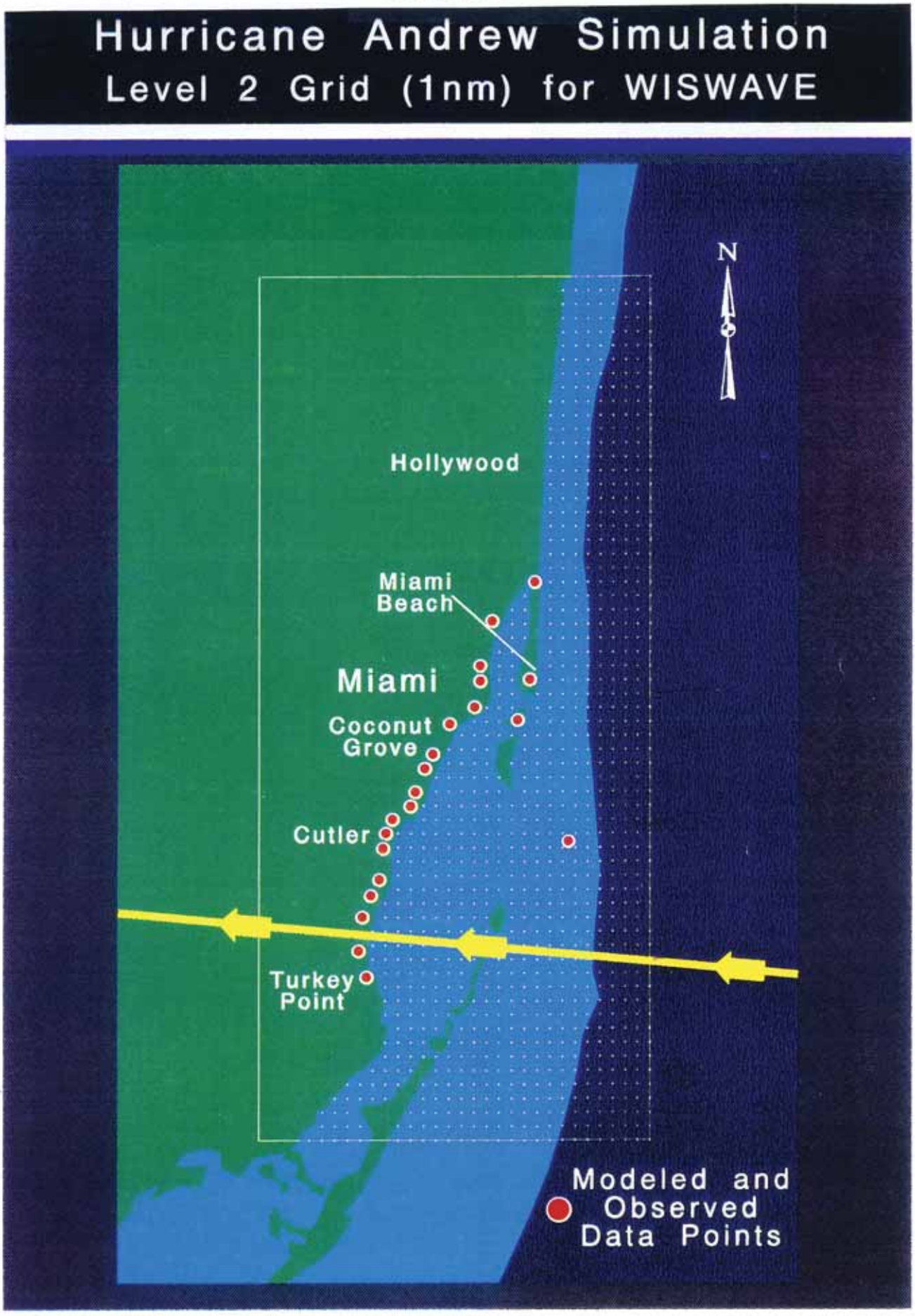
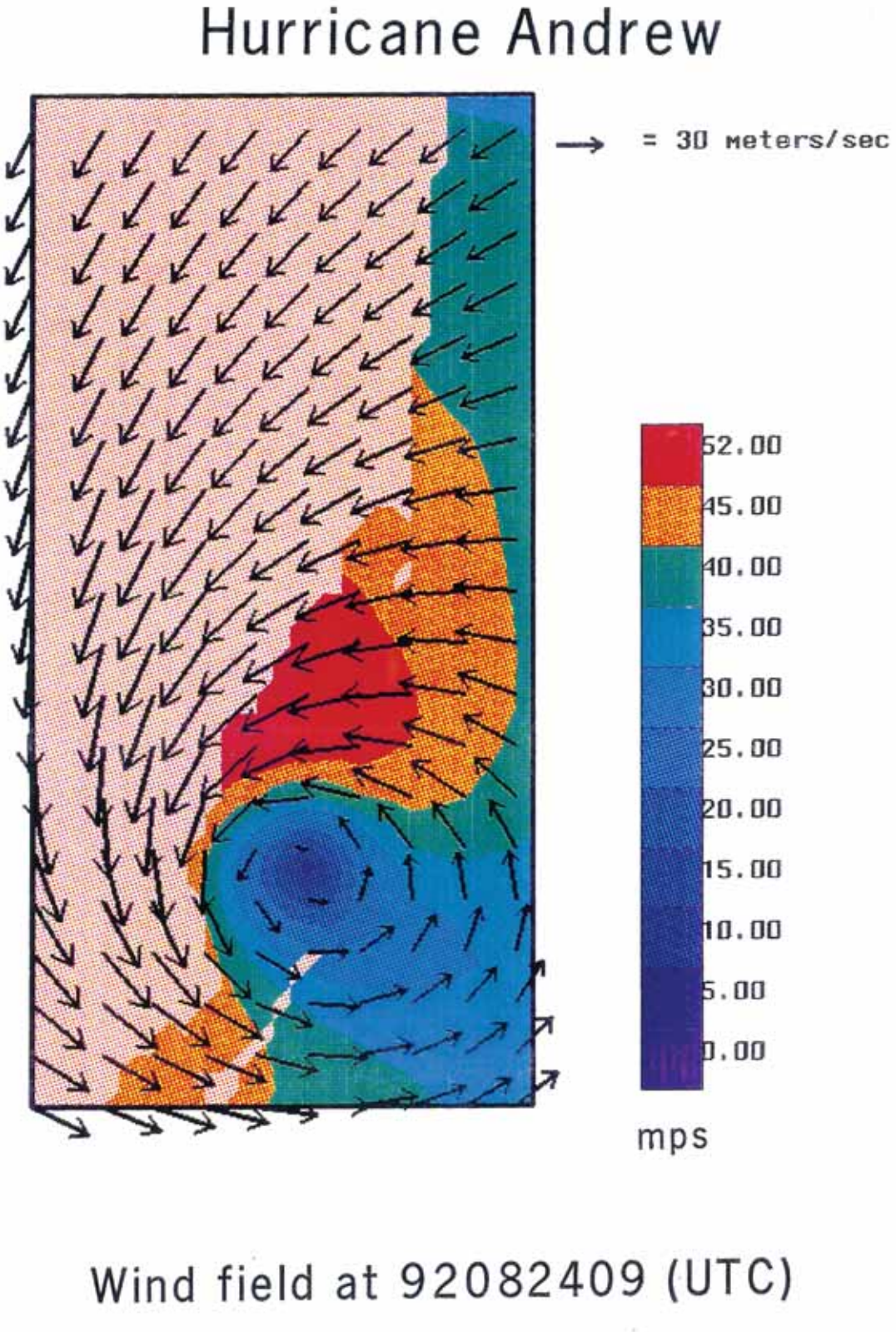

Hurricane Andrew Simulation
Level 2 Grid (1nm) for WISWAVE
N
Hollywood
Miami Beach
Miami
Coconut Grove
Cutler
Turkey Point
Modeled and Observed Data Points

FIGURE 28
NUMERICAL WIND FIELD AT LANDFALL



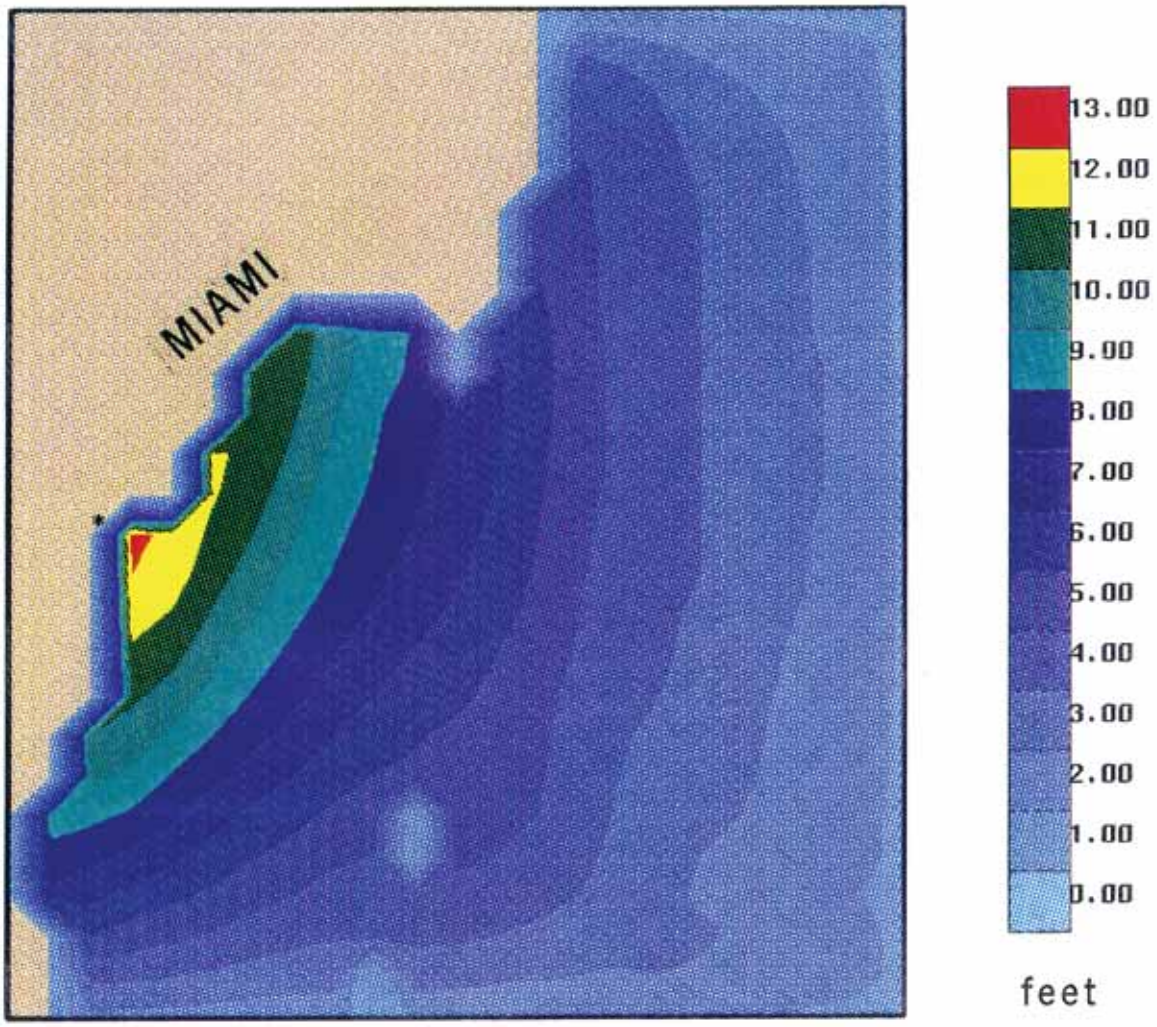


FIGURE 29
NUMERICAL SURGE AT LANDFALL

FIGURE 30
HURRICANE ANDREW
WIND SPEED AND STORM SURGE COMPARISONS

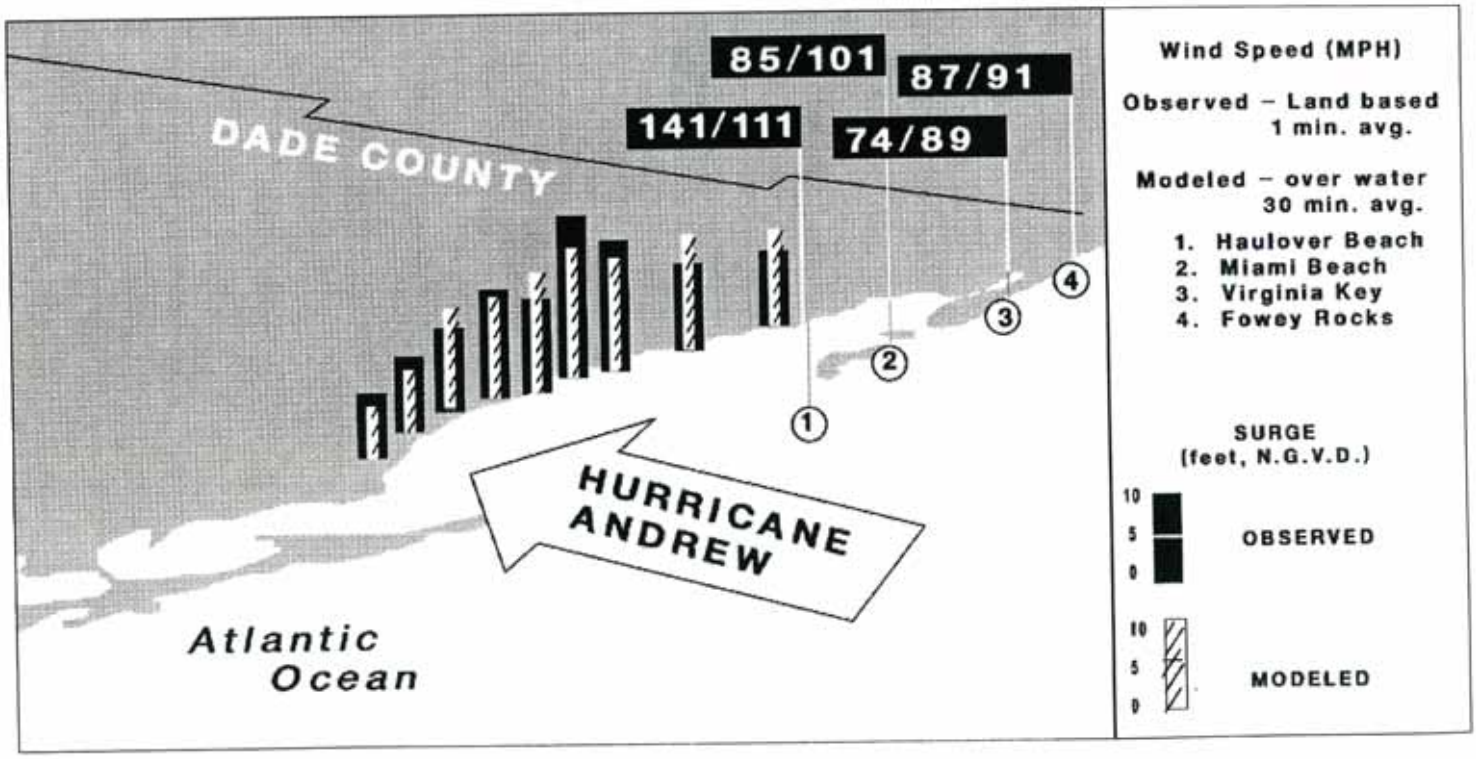
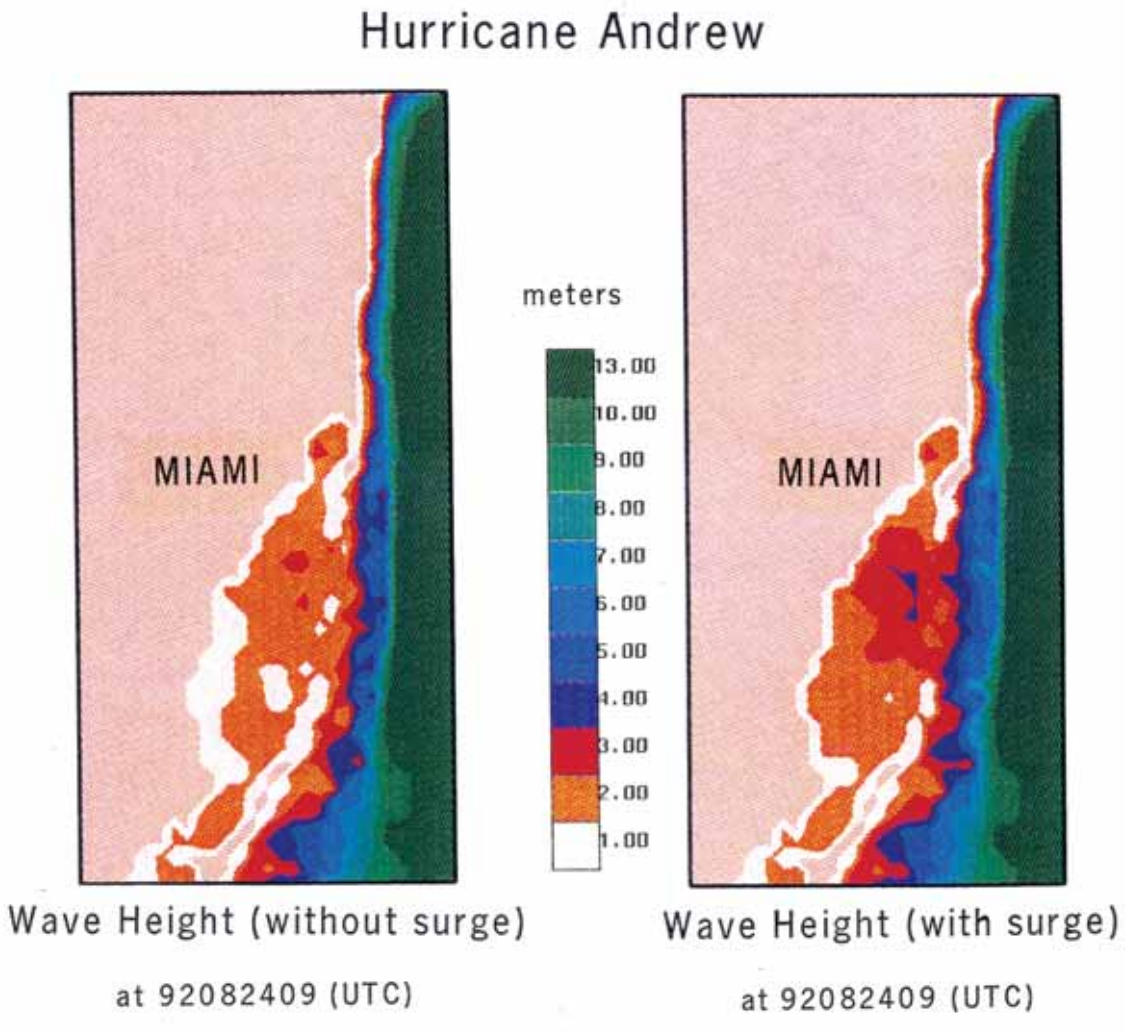


FIGURE 31


Hurricane Andrew
MIAMI
meters
13.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
MIAMI
Wave Height (without surge)
at 92082409 (UTC)
Wave Height (with surge)
at 92082409 (UTC)

ADDITIONAL INVESTIGATIONS

40. Broward County performed a survey of the Hollywood and Hallandale beaches on Saturday, 22 August 1992 prior to the arrival of the storm. Broward County has surveyed the beaches of Hollywood, Hallandale, J.U. Lloyd State Park, Pompano and Lauderdale by the Sea. Dr. Bob Dean and Dr. Hisang Wang of the University of Florida traveled to Dade County to conduct an inspection of the beaches of the county starting on Monday, 31 August 1992.

SHORE PROTECTION PROJECT REHABILITATION

41. A public notice was issued on 28 August 1992 advising state and county agencies of Florida that Federal assistance was available under Public Law 84-99 to rehabilitate Federal and non-Federal flood control or shore protection works damaged by Hurricane Andrew. Several criteria would have to be met for the projects to be eligible. The first step was for the project sponsors to request in writing PL 84-99 assistance. In response, seven requests were received from Broward (2) and Dade County (5) officials to rehabilitate shore protection projects. Funds and approval to proceed with the rehabilitation studies were requested 10 September 1992. Funds totaling $195,000 were provided to the District to perform the rehabilitation studies. The rehabilitation studies for the projects in Broward County indicated that rehabilitation of the beaches in Broward County are not necessary. The Dade County studies have been completed and are under review within the U.S. Army Corps of Engineers. The reports will be available for public distribution following the Corps review.

HURRICANE IMPACTS ON THE GULF COAST OF FLORIDA

42. The aerial inspections of the gulf coast were made at the time of high tide along the gulf coast. Waves at the time of the inspections were between 2 to 4 feet in height. In general, the beaches along the gulf coast were not impacted by the hurricane to any appreciable degree. A minor scarp of one to two feet was observed in the beach or dune along much of the area. In areas hardened by coastal armor, waves were breaking on the armor, or wave run up was occurring up to the toe of the structures. This was particularly true in known problem areas such as Anna Maria Island and Venice.

43. There was evidence of surge and wave overtopping on the barrier islands in areas of lower elevations, typically on the northern ends of each island. About 500 feet of coastal highway was observed to have been damaged, and one lane of the highway was closed in Sarasota County. There was progressively less

damage to the beaches as one traveled from Anna Maria Island in Manatee County in the north, to Marco Island in Collier County to the south. Since the storm was an exiting storm on the gulf coast, the beach scarp was likely caused by waves generated by the hurricane after it had traveled out into the gulf.

HURRICANE IMPACTS ON THE BEACH NOURISHMENT PROJECTS OF THE SOUTHEAST COAST OF FLORIDA

44. Hurricane impacts on Florida's southeast coast are discussed below. The impacts are described project by project from Key Biscayne to the south and proceeding northward. The geometric center of the storm passed over Elliot Key, an island which is part of the northernmost Florida Keys archipelago south of Key Biscayne. Although not part of any beach nourishment project, the impacts to Elliot Key are also presented in the following discussion. Representative beach profile surveys for the various shore protection projects in Dade and Broward counties are included in Appendix A. The graphs depict plots of the pre- and post-storm surveys and the project design templates.

ELLIOT KEY

45. Elliot Key lies within the northernmost Florida Keys archipelago and is part of Biscayne National Park. The island is characterized by numerous small pocket beaches of carbonate material perched over the bedrock of the Key Largo limestone formation. The carbonate beach sediments are derived substantially from the erosion of exposed limestone rock and from the fragmented remains of corals, shells and calcareous algae. Data on the shoreline processes are not available as these pocket beaches remain largely unstudied.

46. The storm tide was measured near the north end of the island at Point Adelle to be +9.2 ft. NGVD. The island was completely inundated by the storm tide resulting in the transport of surface sediments across the island and into Biscayne Bay. Heavy damage to native vegetation occurred throughout the island. The rising and falling storm tide and the turbulent wave activity transported sediments from the area between the island and the barrier reef (Hawk Channel) onto Elliot Key and offshore of the reef. Both erosion and accretion of the shoreline was apparent, however, the observed shoreline changes were not large in magnitude as the limestone formation provides for geological control over the shoreline position.

KEY BISCAYNE (3 Projects)

47. Project Description. - There are three storm damage reduction projects for Key Biscayne. The projects from south to north are as follows:

48. Project (1) - The Cape Florida Section 103 Beach Erosion Control project provides for Federal participation in the initial construction costs of a 283 foot stone revetment. The project protects the historic lighthouse at the southerly end of Cape Florida State Park.

49. The easterly segment of the revetment has three layers of stone: (1) a four foot layer of 1,000 to 6,000 lb rip rap stone, (2) a 1.5 foot layer of 1 to 16 inch bedding stone and (3) a layer (thickness varies) of No. 60 to 2 inch filter stone. The crest width is three feet. The apron of this segment of revetment ties into the existing bottom. With the exception of the front of the lighthouse, there is a fifteen foot blanket landward of the seawall at elevation +6.0 MLW which ties in level with the seawall crest. It is comprised of a 1.5 foot layer of 1 to 16 inch bedding stone and a 0.5 foot layer of No. 60 to 2 inch filter stone. The blanket has a 1 on 1.5 slope which ties into the existing ground.

50. The northerly segment of the revetment is composed of two portions, the continuous revetment and the end section. The continuous revetment is similar to the easterly segment except for the following differences:

(1) The rip rap layer is comprised of stone salvaged from around the seawall prior to revetment construction.
(2) The seaward end of the apron is at elevation -1.0 mean low water (MLW).
(3) The filter stone thickness is one foot.
(4) The blanket elevation is at +5.0 MLW.
(5) The crest width is approximately nine feet.

51. The end section has a crest width of three feet and is composed of two layers of stone: 1) an undetermined thickness of salvaged rip rap stone and 2) a two foot layer of 1 to 16 inch bedding stone underlying the rip rap stone. The bedding stone also provides a 1 on 1.5 slope behind the rip rap stone. This section was excavated to -1.0 MLW for stone placement and then backfilled to elevation +5.0 MLW along both sides and at the end of the stone mound. There is no blanket.

52. The Cape Florida Beach Erosion Control Project provides protection for a 10 year storm. The revetment has two separable design segments: the easterly segment in which the revetment ties into the seawall and the northerly segment which ties into the existing ground. In all cases, the crest elevation is +5.0 (MLW) with a two foot apron. The side slopes are 1 on 2 for the armor stone and the apron toe.

53. Project 2 - The Key Biscayne Section 103 Beach Erosion Control project provides for initial restoration and periodic nourishment for 2.4 miles of Key Biscayne from the southern limit

of Crandon Park to the tip of the southern end of Key Biscayne, with a terminal groin at the Cape Florida lighthouse.

54. The design berm elevation is +5.7 feet (ft) National Geodetic Vertical Datum (NGVD) with a seaward slope of 1 vertical (V) to 14 horizontal (H) from the berm crest to intersection with the existing pre-project profile. Between Crandon Park and Bill Baggs Cape Florida State Park, the berm width varies between 65 and 155 ft to provide a 25 ft berm seaward of the Erosion Control Line (ECL). In Bill Baggs Cape Florida State Park, the berm width varies between 50 and 120 ft. There is a 1,750 ft shoreline segment within the state park, approximately 2,900 ft north of the terminal groin, which provides a dune at elevation +5.7 ft NGVD, with a land ward slope of 1V to 5H and a berm width of 10 ft.

55. Also included in the authorized project was construction of a terminal groin at Cape Florida Lighthouse and additional toe protection for the revetment at the lighthouse. The terminal groin ties into the existing revetment and the crest extends 100 ft seaward. At 90 ft from the existing revetment, the groin makes a 135 degree northward turn. It has a crest width of 7 ft at elevation +4.7 ft NGVD. There are 3 layers of stone: (1) a 5 ft layer of 1,000 to 6,000 pound (lb) armor stone (side slopes 1V to 2H), (2) a minimum 3 ft layer (height varies) of 50 to 750 lb core stone, and (3) a 2 ft layer of 1 to 12 inch (in) bedding stone (side slopes 1V to 2H to existing ground). The minimum stone densities are 165 lb/cubic ft (cf) for the armor and core stone and 148 lb/cf for the bedding stone. The northeastern side of the terminal groin has a 5 ft apron. The southwestern side has a 6 in to 3 ft layer of 150 to 1,000 lb toe protection stone (165 lb/cf) with a 10 ft surface and side slopes of 1V to 2H to existing ground. The toe protection extends around the southern side of the terminal groin and along 170 ft of the eastern segment of the existing revetment.

56. The Key Biscayne shore protection project was constructed in 1987. It included beach renourishment along 2.4 miles of the southern shoreline of Key Biscayne between the southern boundary of Crandon Park and the Cape Florida Lighthouse, excluding a 1,600 foot shoreline segment within Bill Baggs Cape Florida State Park. The 1,600 ft segment received no fill due to natural accretion in the area and heavy sea grass growth directly offshore.

57. The authority provided for Federal participation in the initial construction costs for beach restoration with a terminal groin. The purpose of the beach restoration is to provide storm damage reduction to structural improvements threatened by coastal erosion and storm effects. The terminal groin is provided to reduce the periodic nourishment quantities required to maintain the required beach fill dimensions.

58. Project 3 - A project for the northerly 1.9 miles of Key Biscayne was authorized in 1962 in combination with a project for Virginia Key, and was constructed in 1969. The project is described in greater detail in the Virginia Key project discussion.

59. Project Performance. The shore protection projects for Key Biscayne were constructed to an elevation of +5.7 feet NGVD. Surge levels for the island are reported up to +9.3 feet NGVD. The island was overtopped by the storm surge. The groin at the south end of the island appears intact, but some of the armor stone and foundation on the south side of the groin were damaged. Although the island was overtopped, the beach appeared to be unaffected to any significant degree based on aerial inspections. Key Biscayne (2.4 mile project constructed in 1987) gained a total net volume of sand of 26,000 cubic yards. The total cut volume was -35,000 cubic yards (-3.1 cubic yards per foot of shoreline) while the total fill volume was 61,000 cubic yards (5.4 cubic yards per foot of shoreline). Above NGVD, the net volume of sand gained was 4.8 cubic yards per foot of shoreline. The net volume of sand gained below NGVD was 1.0 cubic yards per foot of shoreline.

VIRGINIA KEY

60. Project Description. - The Virginia Key and Key Biscayne Beach Erosion Control project provided for Federal participation in periodic nourishment of 1.8 miles of shoreline on Virginia Key and 1.9 miles of shoreline on northern Key Biscayne in addition to deferred construction of three groins on Virginia Key and one on Key Biscayne. Construction of the groins was subject to future determination of their need. The project design provided for a 50 foot extension of the beach berm at elevation +6 feet MLW on the 1.8 mile Virginia Key segment and elevation +7 feet MLW on the 1.9 mile Key Biscayne segment. The average increase in beach width at mean high water was approximately 85 feet. The project provided for a seaward slope of the restored beach of 1 on 20 from berm crest to MLW, thence, 1 on 30 to intersection with the existing bottom.

61. The Virginia Key/Key Biscayne project (1.8/1.9 miles) was authorized in 1962 and constructed in 1969. It included beach nourishment on Virginia Key between DNR monuments R-79 and R-86 and on northern Key Biscayne between DNR monuments R-92 and R101, excluding a 3,200 foot segment fronting Crandon Park (R-96 to R-100). The 3,200 foot segment fronting Crandon Park did not require beach fill as the existing natural beach width in that area approximated the proposed design beach fill. The presence of a large shoal located approximately 650 feet offshore sheltered the beach from wave activity thereby allowing for natural accretion at the beach on the leeward side of the shoal.

The Virginia Key segment was renourished and 13 groins constructed in 1972. The area re-nourished extended from DNR monument R-79 to R-85. The shore protection project for the remainder of Key Biscayne (southern 2.4 miles) was authorized in August 1985. Construction was completed in 1987.

62. Project Performance. The average elevation along Key Biscayne is about 5.7 feet NGVD. The shore protection project for the northern Key Biscayne segment was constructed to an elevation of 5.7 feet NGVD. Surge levels at Key Biscayne were measured to be 8.8 feet NGVD at the northern end and 9.3 feet NGVD at the southern end of the island, indicating that the island was inundated by approximately 3 feet. Scouring was observed along the locally constructed retaining wall for the circular drive at monument R-98 in Crandon Park. The scouring exposed the wall's pile foundation and undermined the fill supporting the roadway, causing the collapse of two 50-foot-long sections of pavement. Concrete slabs which served as foundations for groups of picnic tables located at monument R-97 were undermined by localized scour. Development on the island was substantially impacted by the flooding and high wind speeds.

63. Subsequent to project construction, the project beach at the northerly limit of the Key Biscayne segment (R-92 to R-96) had eroded into the design section while the project beach at the southern end of Crandon Park (R-100 to R101) had accreted material seaward of the design section. Similarly, the post-Hurricane Andrew surveys reflect erosion at the northern end of Key Biscayne and accretion at the southern end of Crandon Park. The net volume loss for the Key Biscayne segment north of Crandon Park was approximately -5,400 cy. The total cut volume in this area was -10,400 cubic yards while the total fill volume was 5,000 cubic yards. Above NGVD, the average volume of sand lost was -1.7 cubic yards per foot of shoreline. The accretion trend at the southerly limit of Crandon Park was also evidenced in the post-storm survey data. The net volume gain for the 0.4 mile segment at the southerly end of Crandon Park was approximately 8,600 cubic yards. The total cut volume in this area was -20,500 cubic yards while the total fill volume was 29,100 cubic yards. Above NGVD, the average volume of sand gained in this area was 8.1 cubic yards per foot of shoreline. These volume changes account for the gains or losses of material from only the dry beach area as the survey data used to quantitatively assess the impacts did not extend below the 0.0 NGVD datum.

64. The average elevation along Virginia Key is about 4.7 feet NGVD. The shore protection project for Virginia Key was constructed to an elevation of 4.7 feet NGVD. Surge levels at northern Key Biscayne, just south of Virginia Key, were reported at 8.8 feet NGVD. Storm surge overtopping occurred throughout the island. Development on the island was substantially impacted by the flooding and winds.

65. Post-storm inspection revealed that the area of most significant overwash appeared to be along the northern tip of the island, near monuments R79 and R80, with sediments transported over the island into the open lagoon behind the barrier beach. The groin field between DNR monuments R79 and R84 appeared to hold the beach. The net volume loss for the Virginia Key segment was approximately 11,000 cy. The total cut volume was -11,800 cubic yards (-1.8 cubic yards per foot of shoreline) while the total fill volume was 900 cubic yards (0.1 cubic yards per foot of shoreline). Above NGVD, the net volume of sand lost was -1.8 cubic yards per foot of shoreline. These volume changes account for the gains or losses of material from only the dry beach area as the survey data used to quantitatively assess the impacts did not extend below the 0.0 NGVD datum. Although the island was overtopped, the beach appeared to be unaffected to any significant degree. The rubble-mound groin structures on Virginia Key appeared to be undamaged.

FISHER ISLAND[1]

66. Project Description. Fisher Island is a private residential and resort development located south of Miami Beach and Government Cut in Dade County, Florida. The island's private developer, Island Developers Inc., funded the design and construction of a beach restoration project. Construction of the project was completed in April 1991. The project fill area included 2,060 ft of the island's Atlantic shoreline divided into 6 cells, each stabilized by T-head rubble mound groins. Upon completion of the construction of the groins, approximately 43,000 cubic yards of oolitic aragonite was barged from the Bahamas and used to fill the cells. A physical monitoring program was designed in accordance with the conditions and requirements of the Florida Department of Natural Resources permit. The plan requires the collection of beach profiles, aerial photography, and sediment samples at spacial intervals on a semi-annual basis for the first 2 years after project construction and annually for the two years thereafter.

67. Project Performance. Data was collected in September 1992 for the second half of 1992 monitoring period to determine the effects of Hurricane Andrew. Analysis of the physical data collected indicates that there is less than a 1 percent difference between the calculated in-place fill volumes for the post-project and September 1992 surveys. The net volume changes above and below +2.0 ft NGVD were -1,640 cubic yards and +1,970 cubic yards, respectively. The net change in volume for the project area was +330 cubic yards. The loss of material above +2.0 ft

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[1] Olsen Associates, Inc., "Fisher Island, Florida - Beach Restoration Physical Monitoring Report No.2", January 1993.

NGVD can be attributed to the wind-blown and overwash losses of material landward of the project boundary. The increase in volume in the profile toe can be attributable to seasonal cross-shore sand migration and hurricane-driven migration of sand from the shallow, nearshore seabeds toward the island shoreline. Significant contamination of native material was observed in the toe samples collected subsequent to the storm event in support of this conclusion.

68. The groins were sufficiently damaged to warrant the procurement of emergency permits for beach grading and reconstruction of the rock groins to meet the original design specifications. Groin repair was completed on October 13, 1992. In summary, the notable project impacts from Hurricane Andrew include the landward displacement of beach sediment due to wind-blown and overwash effects, displacement damage to the rubble groin structures, flattening of the average foreshore beach slope and a gain of sediment in the profile toe.

DADE COUNTY BEACH EROSION AND HURRICANE PROTECTION PROJECT

69. Project Description The Dade County hurricane and storm damage reduction project was authorized in 1968. The hurricane project segment consists of restoration and periodic nourishment of 9.3 miles of shoreline from Government Cut north to Bakers Haulover Inlet for the communities of Miami Beach, Surfside and Bal Harbour. The project calls for a protective dune with a 20-foot crown width at elevation 11.5 feet MLW and side slopes of 1 on 5 down to a protective beach with a berm 50 feet in width at +9 feet MLW. The storm damage reduction portions of the Dade County project for the Haulover Park and Sunny Isles segments are discussed separately below. The total length of the project, including Haulover Park and Sunny Isles, is 13 miles.

70. The project segment for Bal Harbour (0.85 miles) was completed by local interests in 1975. The remaining 9.65 miles of the Dade County project was completed under five separate contracts between 1977 and 1982, with placement of 12.3 million cubic yards of material. The total initial fill placed, including Bal Harbour, was 15.8 million cubic yards of sand. Several sections of the project have required minor renourishment since 1982. The Dade County North of Haulover project (Sunny Isles 2.46 miles) was added to the Dade County project in 1985. The initial construction of Sunny Isles was completed in 1988.

71. The 9.3 mile hurricane protection project segment is designed to protect against a hurricane with a central pressure of 27.5 inches, a radius of maximum winds of 37.5 miles, a forward speed of 13 miles an hour, and maximum overwater wind speed of 104 miles per hour. These parameters result in a design still water level of 7.4 feet MLW. This tide, combined with

expected wave run up resulted in a design dune height of 11.5 feet MLW for a no-overtopping condition.

72. Project Performance - The 9.3 mile project segment from Government Cut to Bakers Haulover Inlet was generally in good condition. Exposed roots and pre-storm ground line marks observed on palm trees and the exposure of the upland portion of an old groin indicated that the berm elevation had been reduced along the project shoreline at Bal Harbour. The exposure of rocks on the dry beach, which were present in the initial fill material and subsequently covered with more suitable material prior to completion of initial construction, was indicative of a loss of material from the berm along the shoreline at Surfside. The accretion of material at the toe of the hurricane dune feature was evidenced along Miami Beach by the burial of dune vegetation with a few inches of sand. Approximately 200 feet of timber pile-supported boardwalk and access stairs adjacent to the Government Cut north jetty sustained heavy damage due to scouring and wave impact during the storm.

73. Figure 11 depicts the tidal gage record from the gage at Bakers Haulover Inlet. Peak surge at Bakers Haulover Inlet at the northern end of this project segment was 5.1 feet NGVD. As mentioned previously, storm surge was measured at 8.8 feet NGVD at the northern end of Key Biscayne. Thus, the storm surge along this segment of the project is estimated to have ranged from 5.1 feet NGVD at the northern end to approximately 8.5 feet NGVD at the southern end. The crest elevation of the hurricane dune feature being 10.2 feet NGVD prevented wave overtopping during the storm event, with the exception of minor overtopping observed at monument R-35. The dune appeared to be intact along the entire project. The debris line was generally at the seaward foot of the dune. There were several sections of the project where the dry beach width was about half the width in comparison to the rest of the beach. DNR survey crews report that the beach and dune appear to have accumulated sand in some places.

74. Pre- and post-storm surveys of the beach were examined to determine the extent of the erosion caused by the hurricane. The 9.3 mile project segment lost a total net volume of approximately 176,000 cubic yards of sand. The total cut volume was -776,000 cubic yards (-15.8 cubic yards per foot of shoreline) while the total fill volume was approximately 600,000 cubic yards (12.2 cubic yards per foot of shoreline). Above MLW, the average volume of sand lost was -4.1 cubic yards per foot of shoreline. The average volume of sand gained below MLW was 0.2 cubic yards per foot of shoreline.

75. Analysis of the physical data collected indicates that isolated sections of this project segment experienced significant losses from the design section as a result of Hurricane Andrew. Those areas which experienced the highest losses of material from

the storm are 7,000 feet of shoreline between DNR monuments R32 and R37 in Surfside, 3,000 feet of shoreline between monuments R54 and T3 in Miami Beach and 1,500 feet of shoreline between monuments R53+537 and R54 near the Government Cut north jetty. The volume of material eroded from these "hotspot" areas is summarized in Table 8. Outside of these hotspot areas, the effects of the storm along the segment of the project which incorporates the protective hurricane dune feature were relatively uniform and consisted of erosion of the seaward edge of the berm and accretion of material in the offshore bar.

76. HAULOVER PARK - Project Description. This portion of the Dade County project is 1.2 miles in length and is located on the north side of Bakers Haulover Inlet. The storm damage reduction project consists of initial restoration of Haulover Park with periodic nourishment as needed. This portion of the Dade County project consists of a 50-foot berm at +9 feet MLW, with 1 on 11 slopes to MLW.

77. Project Performance - The beaches appeared to be intact along the length of the park. The debris line was generally located at the landward edge of the project, indicating that the combination of surge and wave run up may have caused some minor overtopping. The elevation of the beach berm is +9 feet MLW. Surveys taken of the beach were examined to determine the extent of the erosion caused by the hurricane.

78. The analysis of pre- and post-storm surveys indicate that the 1.2 mile project segment gained a total net volume of approximately 123,500 cubic yards of sand. The total cut volume was -72,100 cubic yards (-11.4 cubic yards per foot of shoreline) while the total fill volume was approximately 195,600 cubic yards (30.9 cubic yards per foot of shoreline). Above MLW, the average volume of sand lost was -3.6 cubic yards per foot of shoreline. The average volume of sand gained below MLW was 23.0 cubic yards per foot of shoreline.

79. DADE COUNTY NORTH OF HAULOVER (Sunny Isles) - Project Description. - This portion of the Dade County project is 2.5 miles in length and is located north of Haulover Park. The storm damage reduction project provides for initial restoration of Sunny Isles with periodic nourishment as needed. This portion of the Dade County project consists of a 20-foot berm at 9.0 feet MLW, with 1 on 10 slopes to MLW. Initial construction was completed in 1988 and consisted of placement of 1.4 million cubic yards of sand.

80. Project Performance - The beaches appeared to be intact in this area. The debris line was generally at the berm elevation of the project. Surveys taken of the beach were examined to determine the extent of the erosion caused by the hurricane.

81. The analysis of pre- and post-storm surveys indicate that the 2.5 mile project segment at Sunny Isles gained a total net volume of approximately 23,800 cubic yards of sand. The total cut volume was -304,900 cubic yards (-23.1 cubic yards per foot of shoreline) while the total fill volume was approximately 328,700 cubic yards (24.9 cubic yards per foot of shoreline). Above MLW, the average volume of sand lost was -10.4 cubic yards per foot of shoreline. The average volume of sand gained below MLW was 12.1 cubic yards per foot of shoreline.

82. Analysis of the physical data collected indicate that the northern limit of the project experienced significant losses from the design section as a result of Hurricane Andrew. The area which experienced the highest loss of material from the storm are the northernmost 3,000 feet of shoreline between DNR monuments R7 and R10. The volume of material eroded from this "hotspot" area is summarized in Table 8. Being the northerly terminus of the project, this area has historically experienced a high erosion rate due to end losses. Outside of this hotspot area, the effects of the storm along the Sunny Isles segment of the project were relatively uniform and consisted of erosion of the seaward edge of the berm and accretion of material in the offshore bar.

TABLE 8
DADE COUNTY SUMMARY

Location	Length (FT)	Volume (YD^3)	YD^3 / FT	Volume to Restore Design (YD^3)
Sunny Isles	3,000	-55,000	-18	62,500
Surfside	7,000	-210,000	-30	278,500
North Miami Beach	3,000	-23,700	-8	127,800
Miami Beach	1,500	-11,300	-8	25,500
Totals	14,500	-300,000		494,300

83. Dade County Project Performance Summary - The Dade County Beach Erosion Control and Hurricane Protection project performed exceptionally well during Hurricane Andrew. Taken in total, the Dade County shoreline from the north limit of Sunny Isles to Government Cut gained a total net volume of sand of 8,900 cubic yards. The total cut volume was -1,148,400 cubic yards (-16.7 cubic yards per foot of shoreline), while the total fill volume was 1,157,300 cubic yards (16.9 cubic yards per foot of shoreline). Above MLW, the average volume of sand lost was -5.3 cubic yards per foot of shoreline. The average volume of sand gained below MLW was 5.2 cubic yards per foot of shoreline. In general, the effects of

the storm on the beach profile consisted of erosion of the seaward edge of the berm, accretion of material in the offshore bar located approximately 500 feet seaward of the ECL and accretion of material in the upland dune area.

84. For the project as a whole, the volume of material eroded from the seaward portion of the berm balanced the accretion of material in the bar and dune. The project profile was altered but did not experience a large net gain or loss of material. No damage to upland development due to storm surge or wave impact was observed. All property damage landward of the Erosion Control Line (ECL) appeared to be the result of Hurricane Andrew's high speed winds.

BROWARD COUNTY

85. Project Description. - The shore protection project for Broward County was authorized in 1965. The project provided for initial restoration of about nine of the 24 miles within the county, and future nourishment as needed for the entire county. The project authorized three separable segments which were constructed independently of one another; 1) from the north county line to Hillsboro Inlet (Segment I), 2) from Hillsboro Inlet to Port Everglades Inlet (Segment II) and 3) from Port Everglades Harbor to the south county line (Segment III). About 12 miles of beach have been restored in Broward County since 1970. Pompano (5.21 miles) was initially restored in 1970 and renourished in 1983, J.U. Lloyd State Park (1.5 miles) was initially restored in 1976 and renourished in 1989. Hollywood and Hallandale (5.25 miles) was initially restored in 1979, and was renourished in 1990.

86. BROWARD COUNTY, PORT EVERGLADES TO THE SOUTH COUNTY LINE (Segment III) - Project Description. The design berm elevation for the 1.5 mile segment of this reach fronting J.U. Lloyd State Park is 10.0 feet NGVD with a foreshore slope of 1 on 10 to MLW. This design provided for a 75 to 100 foot extension of the pre-project mean high water shoreline. The southern 5.3 miles of the Segment III project, referred to as the Hollywood/Hallandale reach, is designed with a berm elevation of 7.0 feet NGVD with a foreshore slope of 1 on 10 to MLW. The remaining 1.7 mile reach of shoreline at Dania Beach adjacent to the J.U. Lloyd reach of the project has remained stable throughout the period of record for the project and has not been constructed to date.

87. Project Performance. Pre- and post-storm survey data is available from July 14, 1992 and September 15, 1992, respectively, for J.U. Lloyd state park south of Port Everglades. Pre- and post-storm survey data is available from August 18, 1992 and August 31, 1992, respectively, for Hollywood-Hallandale in southern Broward County. Station and elevation data at approximately 1,000 foot intervals were taken from the DNR survey

monuments along the onshore portion of the beach profile to an average depth of -5 feet NGVD. The majority of the profile comparisons indicate that the beach profile experienced erosion above, and accretion below, the +5 ft NGVD contour.

88. Post-storm surveys of the J.U. Lloyd beaches were taken 22 days after the storm. Recovery of the beaches was observed in all beach profile cross-sections except those within the influence of the inlet at Port Everglades. Post-storm observations of the beach profile indicate that the beach berm was overtopped during the storm event.

89. The Hollywood and Hallandale post-storm beach profiles were taken seven days following the storm. At that time, recovery of the beaches is not as evident. Evidence of minor flood damage to shorefront structures and sediment transport across the boardwalk along the Hollywood/Hallandale segment indicate that the beach berm was overtopped by the storm tide and wave runup.

90. Volume changes between the surveys indicate that approximately 1 and 2 cubic yards of sand per foot of shoreline, respectively, for J.U. Lloyd and Hollywood-Hallandale was removed from the onshore portion of the profile. The cut volume for J.U. Lloyd was -34,000 cubic yards and the net volume loss was -11,000 cubic yards. The cut volume for Hollywood-Hallandale was -129,000 cubic yards and the net volume loss was -57,000 cubic yards. This small net volume change of -68,000 cubic yards over 6.8 miles of project area indicates that an average of 1.9 cubic yards per foot of shoreline was lost seaward of the -5 ft NGVD contour or was lost as wind-blown sand. This segment of the project was not adversely affected by the storm.

91. BROWARD COUNTY, HILLSBORO INLET TO PORT EVERGLADES (Segment II) - Project Description. Segment II is 11.5 miles long and includes the cities of Pompano Beach, Sea Ranch Lakes, Lauderdale-By-the-Sea and Fort Lauderdale. The project was authorized to provide a 75 to 125 foot extension of the pre-project MHW shoreline. The design berm elevation is 9.0 feet NGVD with a foreshore slope of 1 on 15 to MLW.

92. Project Performance - A reduction in berm elevation was evidenced by the exposure of the bases of a number of the DNR survey monuments along the project shoreline. The northern half of the reach was not as severely impacted by the storm as the southern reach, which extends south of the Pompano Beach Pier at Lauderdale-by-the-Sea. Other indications of storm impacts included scarping around pockets of vegetation and the presence of rock on the dry beach face which were either brought onshore or uncovered by the storm waves.

93. Pre- and post-storm survey data is available from February 26, 1992 and September 9, 1992, respectively. Station and elevation data at approximately 1,000 foot intervals were taken from the DNR survey monuments along the onshore portion of the beach profile to an average depth of -5 feet NGVD.

94. Volume changes between the surveys indicate that approximately 1 cubic yard of sand per foot of shoreline was removed from the onshore portion of the profile for the 5.2 mile reach. The cut volume was -178,000 cubic yards and the net volume loss was -35,000 cubic yards. Above NGVD, the average volume of sand lost was -3.5 cubic yards per foot of shoreline. The average volume of sand gained below NGVD was 2.8 cubic yards per foot of shoreline.

95. The small net volume change of -35,000 cubic yards over 5.2 miles of project area indicates that an average of 1 cubic yards per foot of shoreline was lost seaward of the -4 ft NGVD contour or was lost as wind-blown sand. This segment of the project was not adversely affected by the storm.

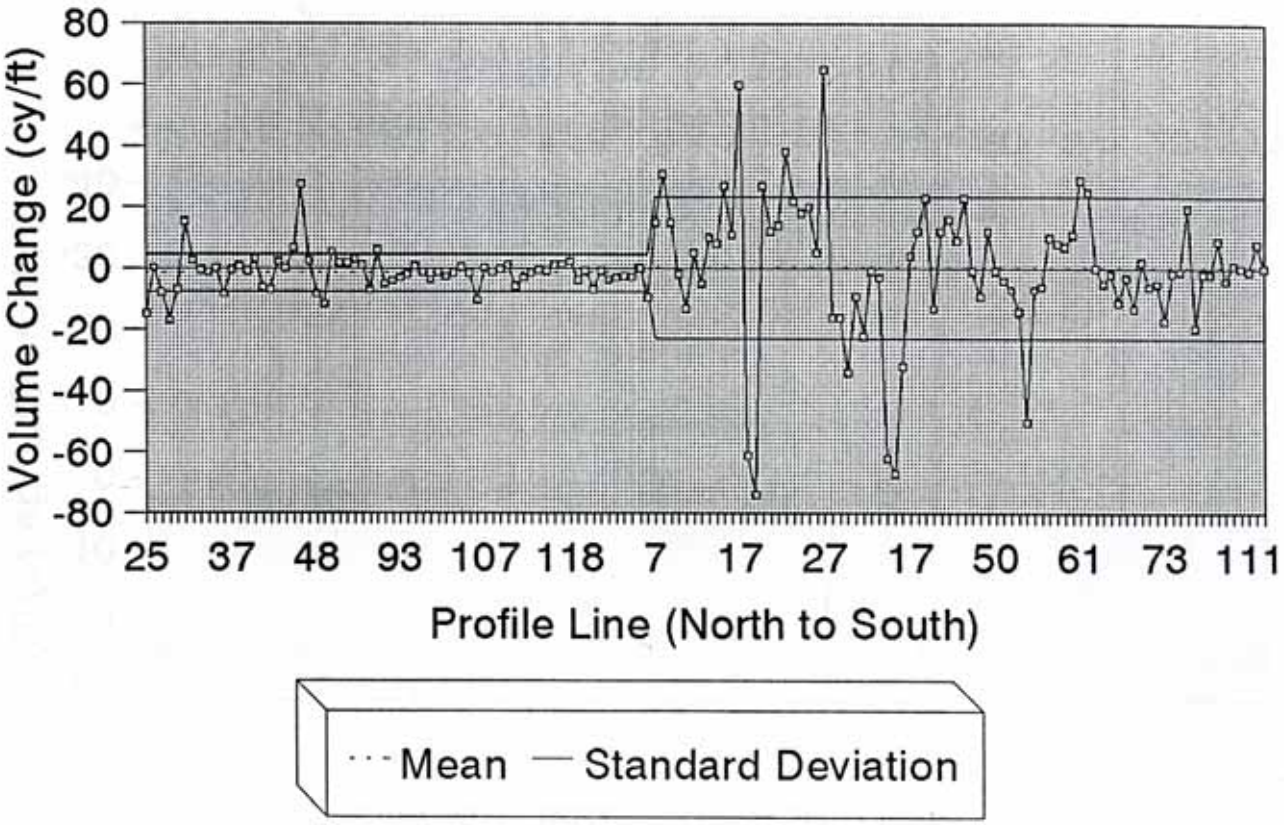
96. Figure 32 depicts the total change in volume, referenced to MHW, computed for the Shore Protection projects in Dade and Broward counties. The data shown starts from the left with the northern limit of the Broward County Segment II project and ends on the right side of the graph with the southern limit of the Key Biscayne project. The locations of the survey monuments used in the Dade County BEC & HP project surveys and shown on the graph, are illustrated in Appendix A.

97. The graph illustrates a distinct change in the magnitudes of volume changes between the Broward County projects and the Dade County project. The Broward County projects experienced a mean volume loss of -1.4 cubic yards per foot of shoreline while the Dade County projects experienced a mean volume increase of 0.3 cubic yards per foot of shoreline.

98. Figure 33 illustrates the change in volume above the MHW contour computed for the Shore Protection projects in Dade and Broward counties. The graph indicates that the Dade County projects experienced greater loss of material from the beach berm portion of the profile than the Broward county projects.

Post Andrew-Total Volume Change

Broward and Dade Counties

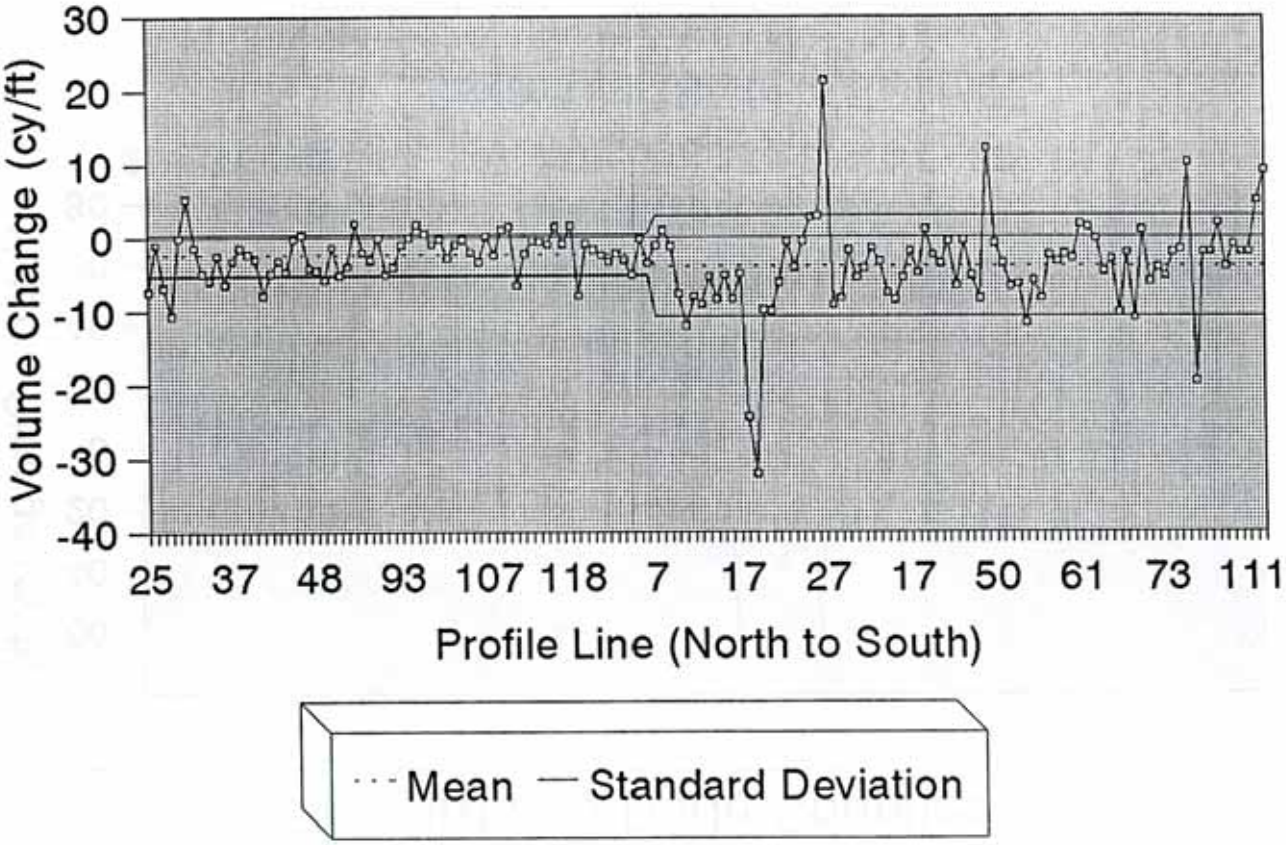


Broward County: Mean = - 1.4, Std Dev = 6.1
Dade County: Mean = 0.3, Std Dev = 23.3

FIGURE 32

Post Andrew-Volume Change Above MHW

Broward and Dade Counties



Broward County: Mean = - 2.3, Std Dev = 2.8
Dade County: Mean = - 3.9, Std Dev = 6.8

FIGURE 33

SUMMARY

The worst impact zone of Hurricane Andrew was generally south of Miami Beach. The barrier islands south of Miami Beach, Virginia Key, Key Biscayne and Elliot Key, were inundated by the storm tide which was measured at 8.8 and 9.0 feet NGVD along Key Biscayne.

The narrow pocket carbonate beaches of the generally rocky shoreline of the impacted upper keys (Soldier Key through Elliot Key) are not subject to significant shoreline change.

Hurricane Andrew passed by quickly - within one high phase of the semi-diurnal astronomical tide.

Key Biscayne and Virginia Key, exposed to the greatest erosive forces, are generally without a prominent barrier dune system, which would have been subject to erosion. These two islands were overtopped.

MAJOR LESSONS LEARNED

Beach Restoration Works - Particularly when all elements are included (beach berm, barrier dune, vegetation, etc.), such as at the Dade County hurricane and storm damage reduction project.

A barrier dune is needed on Key Biscayne. The shore protection project mitigated substantial shorefront damages, but a dune could have prevented or reduced the flooding on the island.

Unlike inland development where "new" often represents "inferior" construction, beach front development which meets the state's coastal building standards generally fared much better during Andrew.

Net excavation seaward of the coastal construction control lines should continue to be prohibited.

DAMAGES PREVENTED

The U.S. Army Corps of Engineers, Jacksonville District shore protection projects prevented an estimated $24.6 million in damages during Hurricane Andrew. The shore protection projects prevented $5 million in damages for the Hollywood-Hallandale project segment in Broward County. The Sunny Isles portion of Dade county was spared $7.6 million in damages. The coastal areas south of Bakers Haulover Inlet to Government Cut which includes Bal Harbor, Surfside and Miami Beach would have experienced an additional $12 million in damages had the Dade County hurricane and storm damage reduction project not been in place.

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U.S. Army Corps of Engineers - Jacksonville District, Rehabilitation Letter Report - Segment III, Broward County, Florida - Florida Shore Protection Project, from Port Everglades to the South County Line, October 26, 1992.

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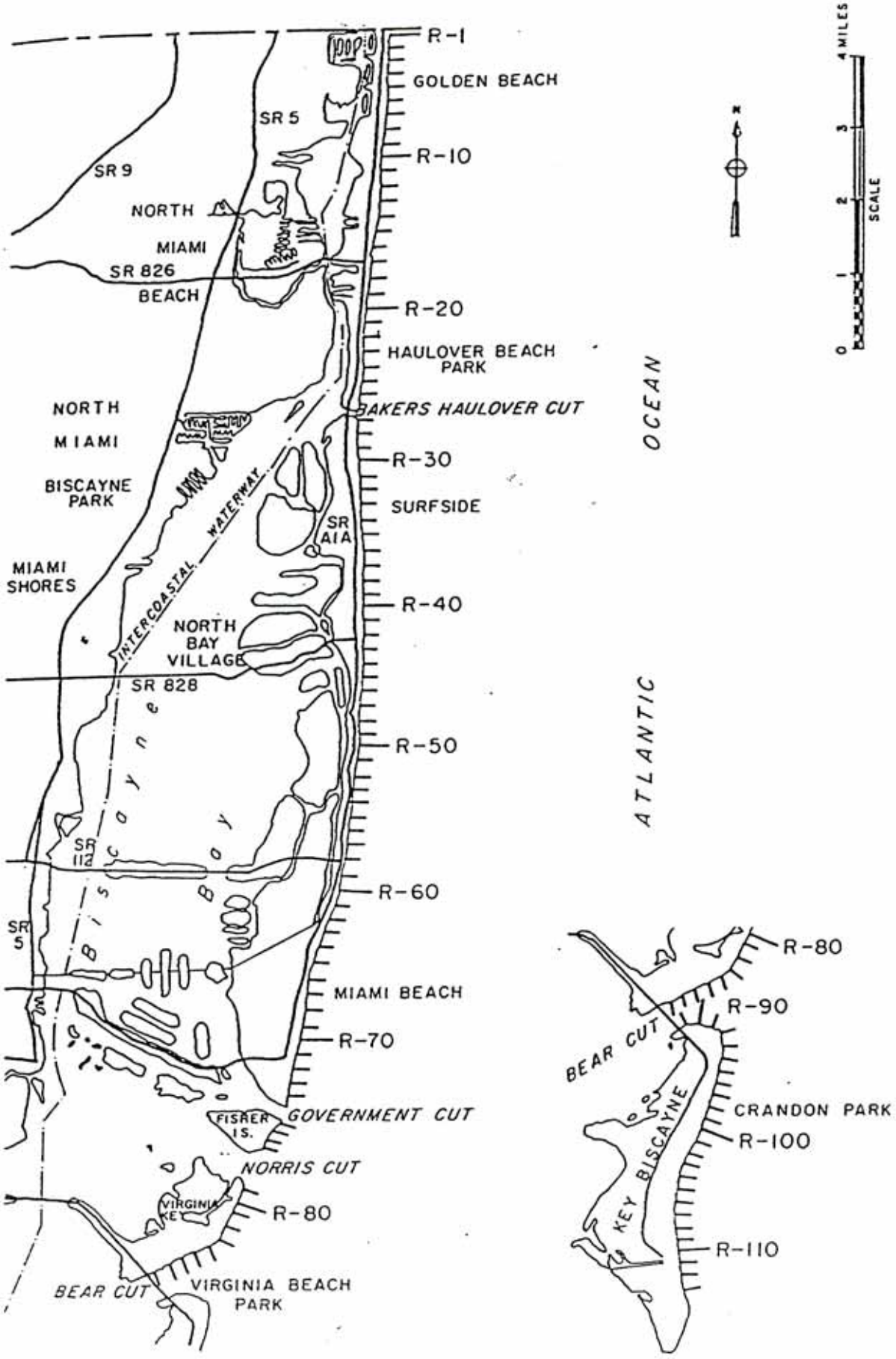
APPENDIX A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SR 5
R-10
SR 9
NORTH MIAMI BEACH
SR 826
R-20
HAULOVER BEACH PARK
BAKERS HAULOVER CUT
NORTH MIAMI
BISCAYNE PARK
R-30
SURFSIDE
SR A1A
INTERCOASTAL WATERWAY
MIAMI SHORES
R-40
NORTH BAY VILLAGE
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SR 112
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SR 5
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NORRIS CUT
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OCEAN
ATLANTIC
BISCAYNE BAY
R-80
R-90
BEAR CUT
CRANDON PARK
R-100
KEY BISCAYNE
R-110
N
0
1
2
3
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SCALE

DADE COUNTY

KEY BISCAYNE TERMINAL GROIN, DADE COUNTY, FLORIDA
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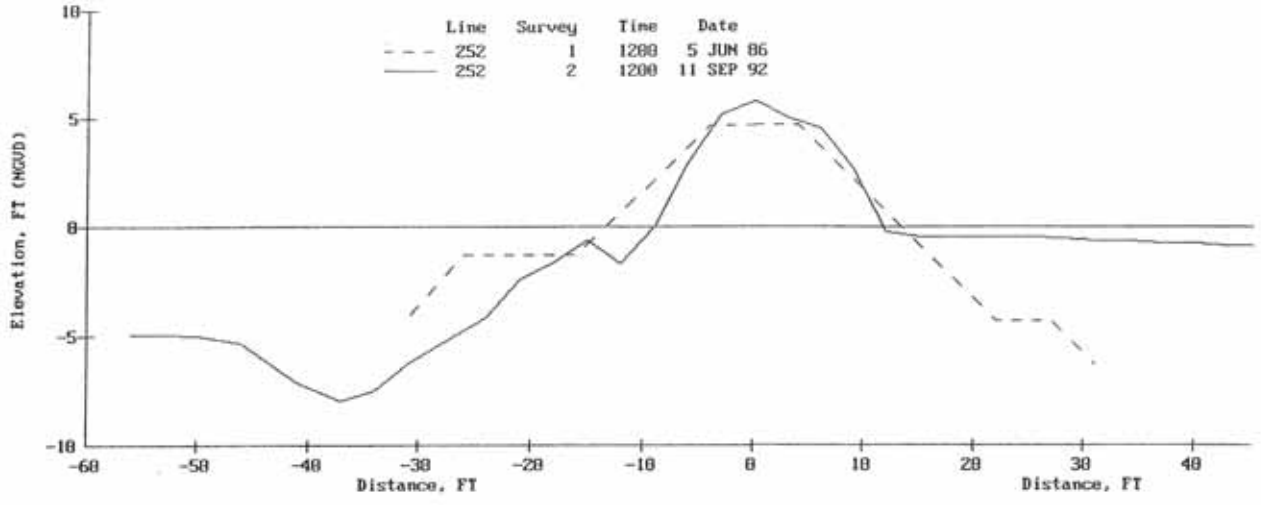

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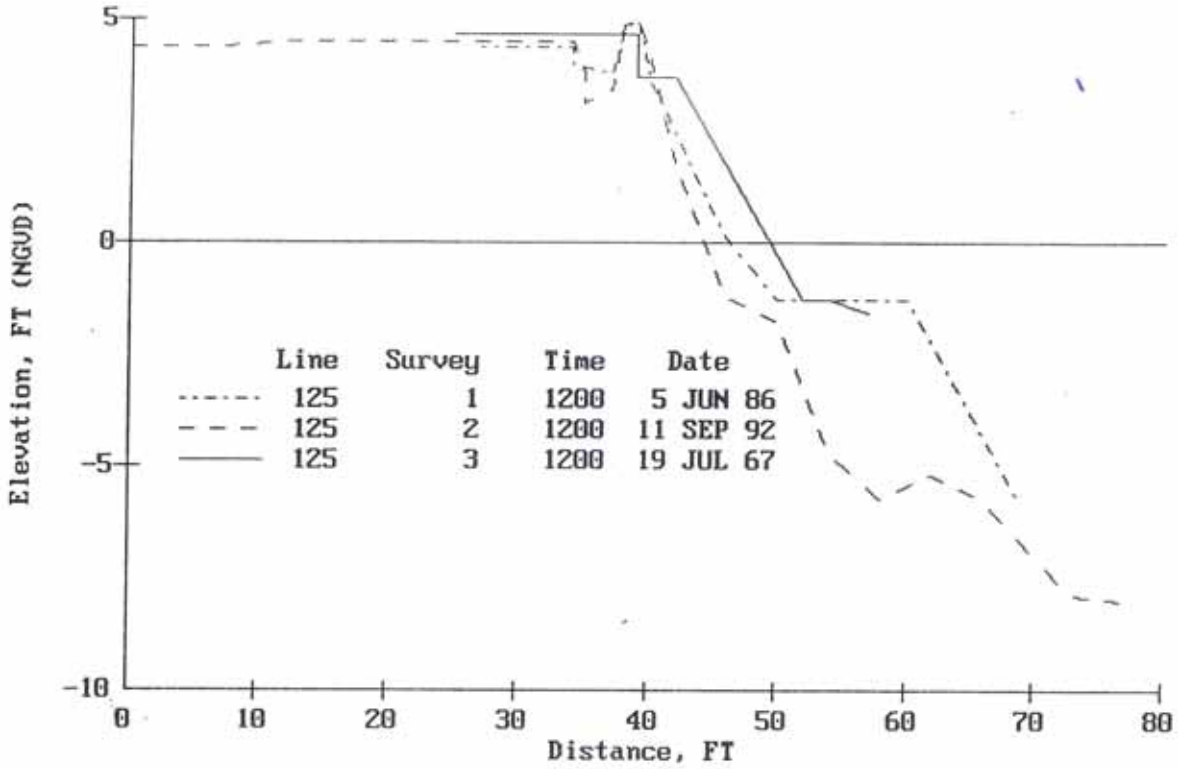

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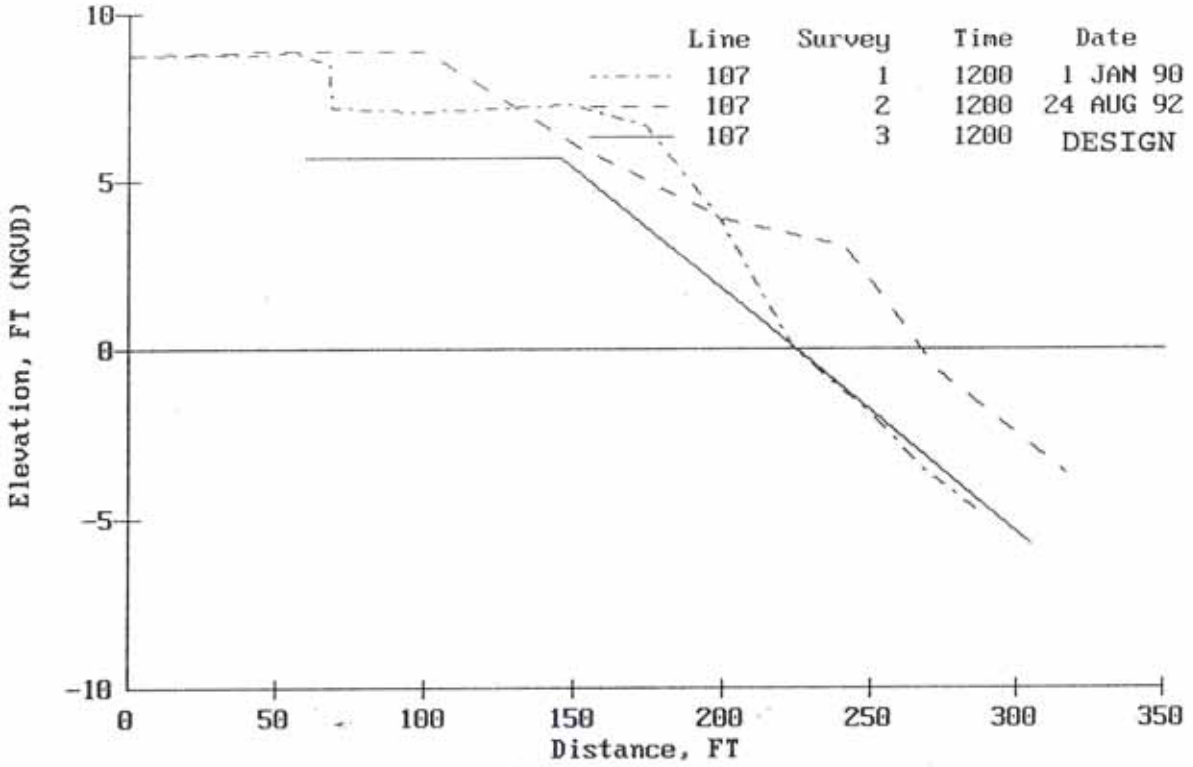

KEY BISCAYNE

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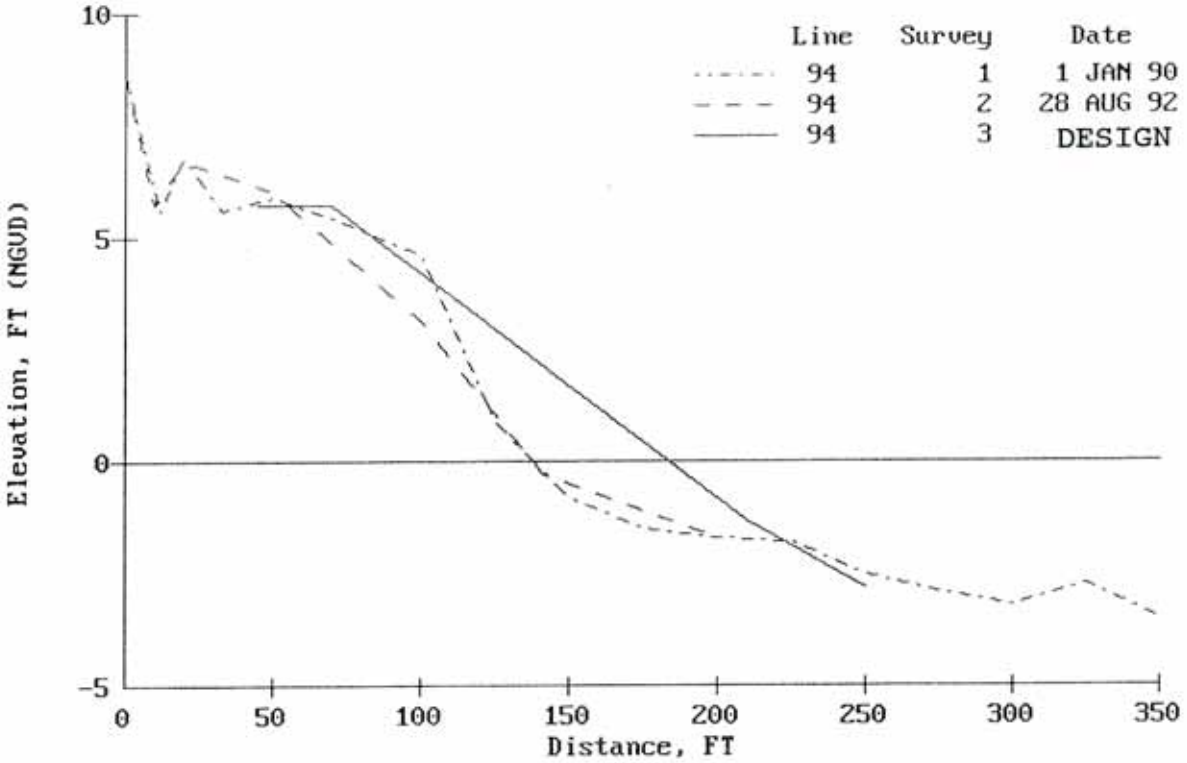

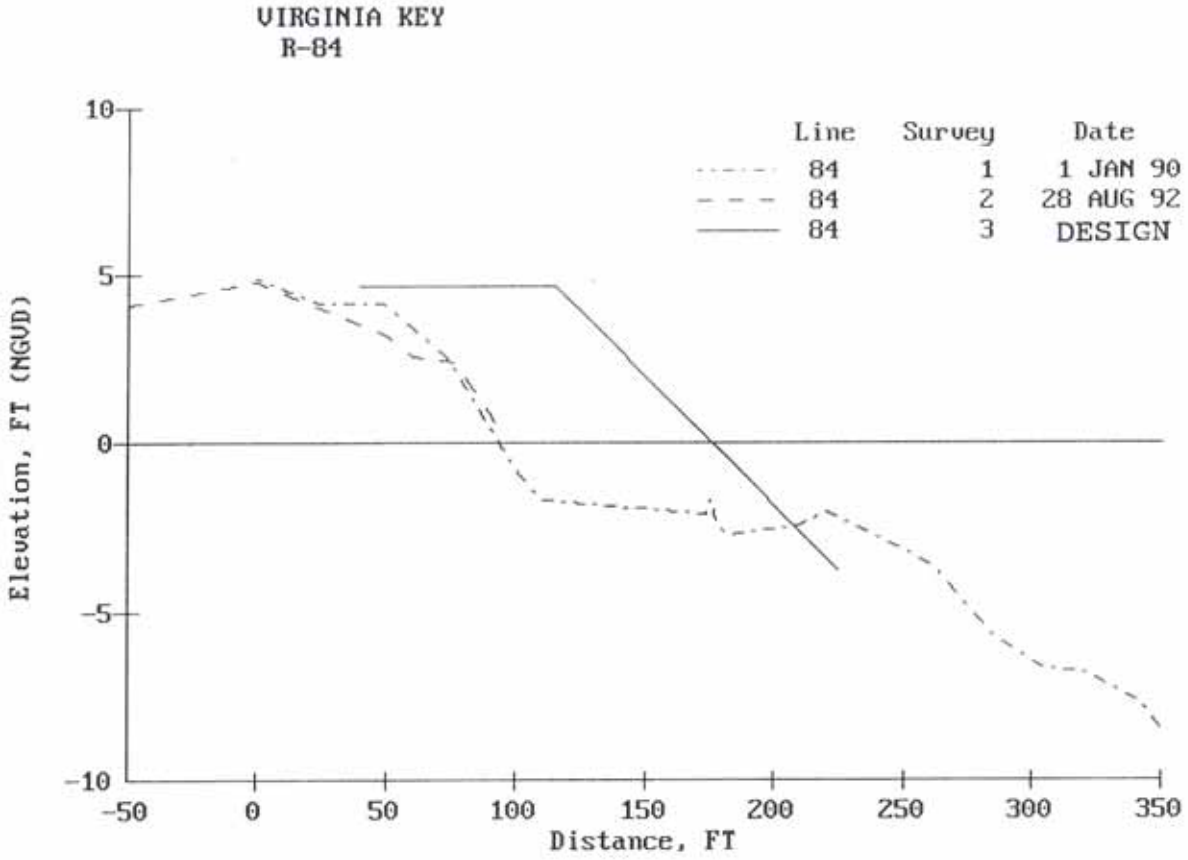
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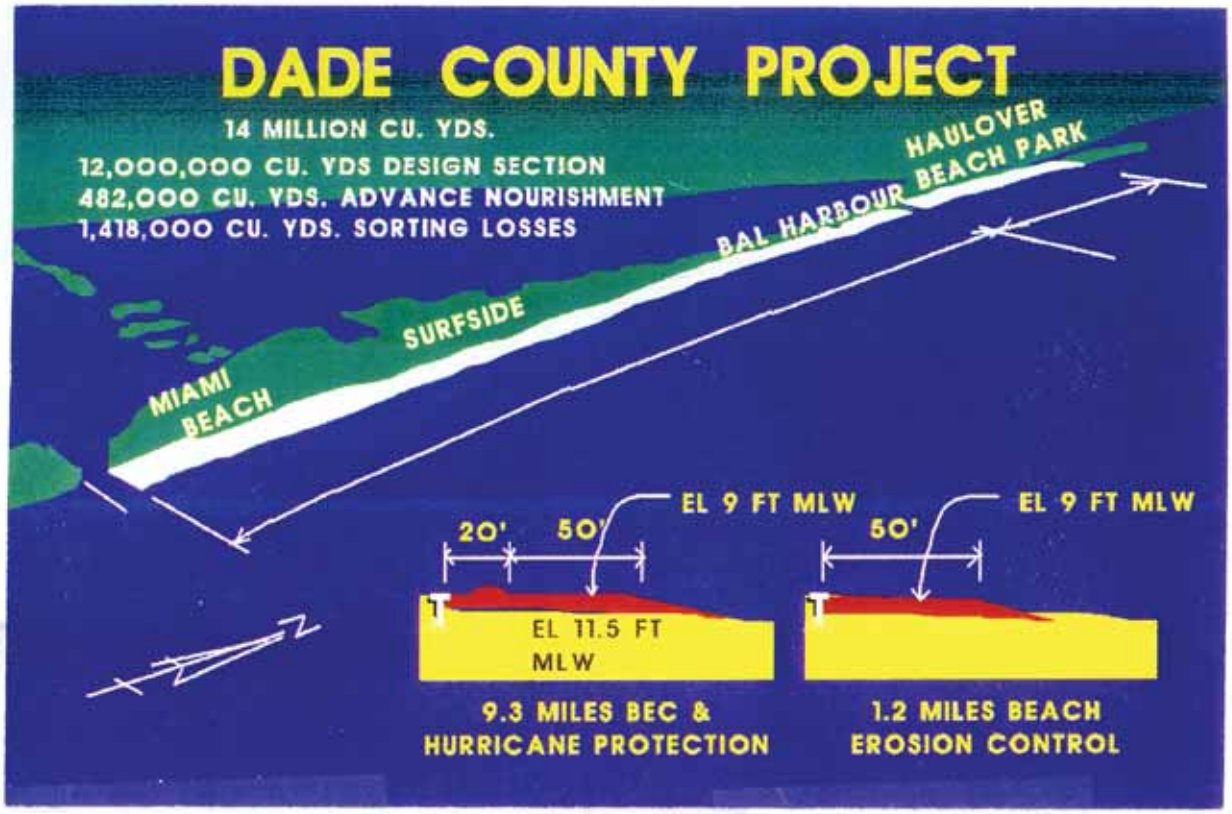

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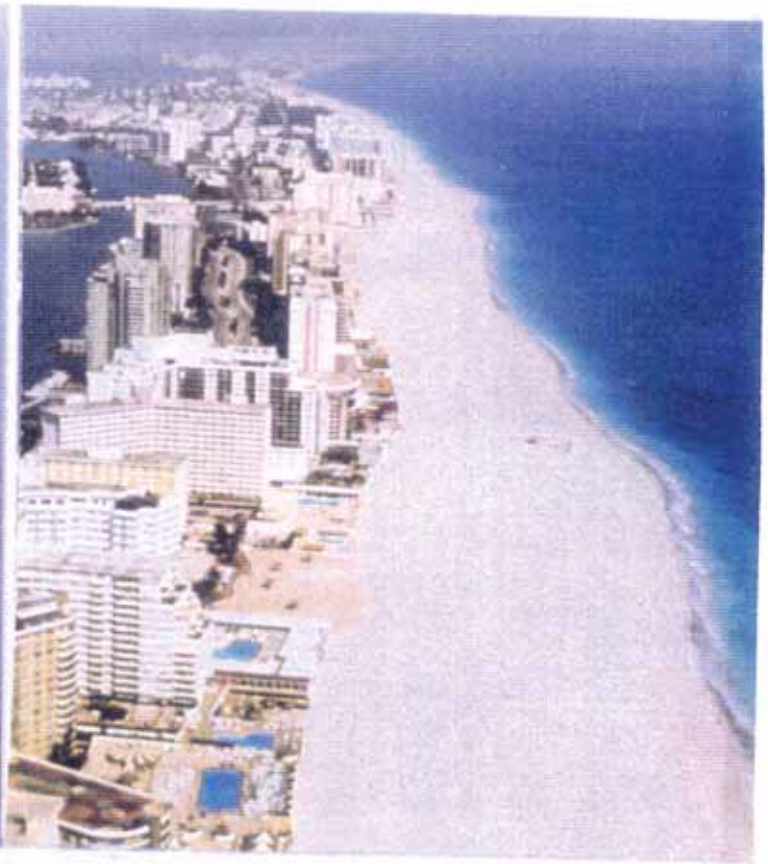

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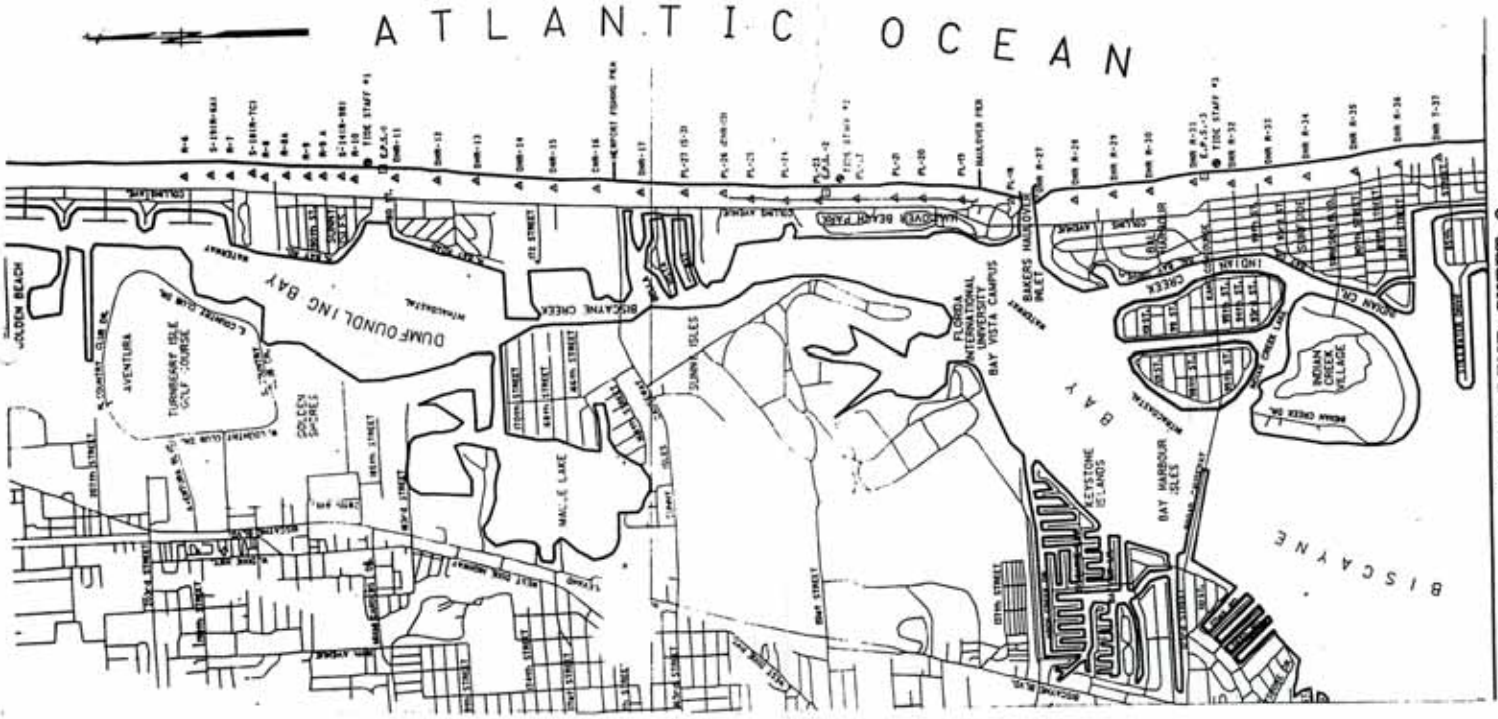

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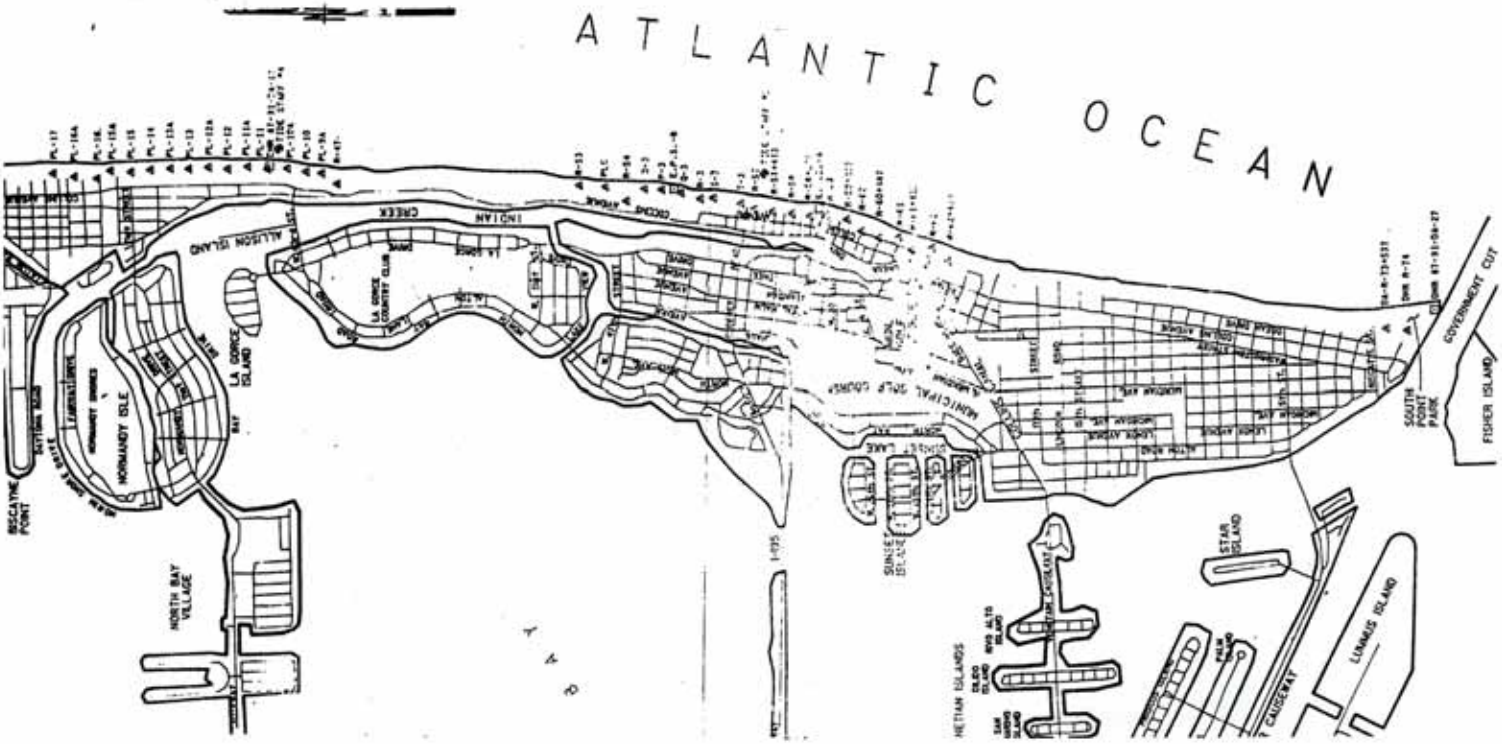

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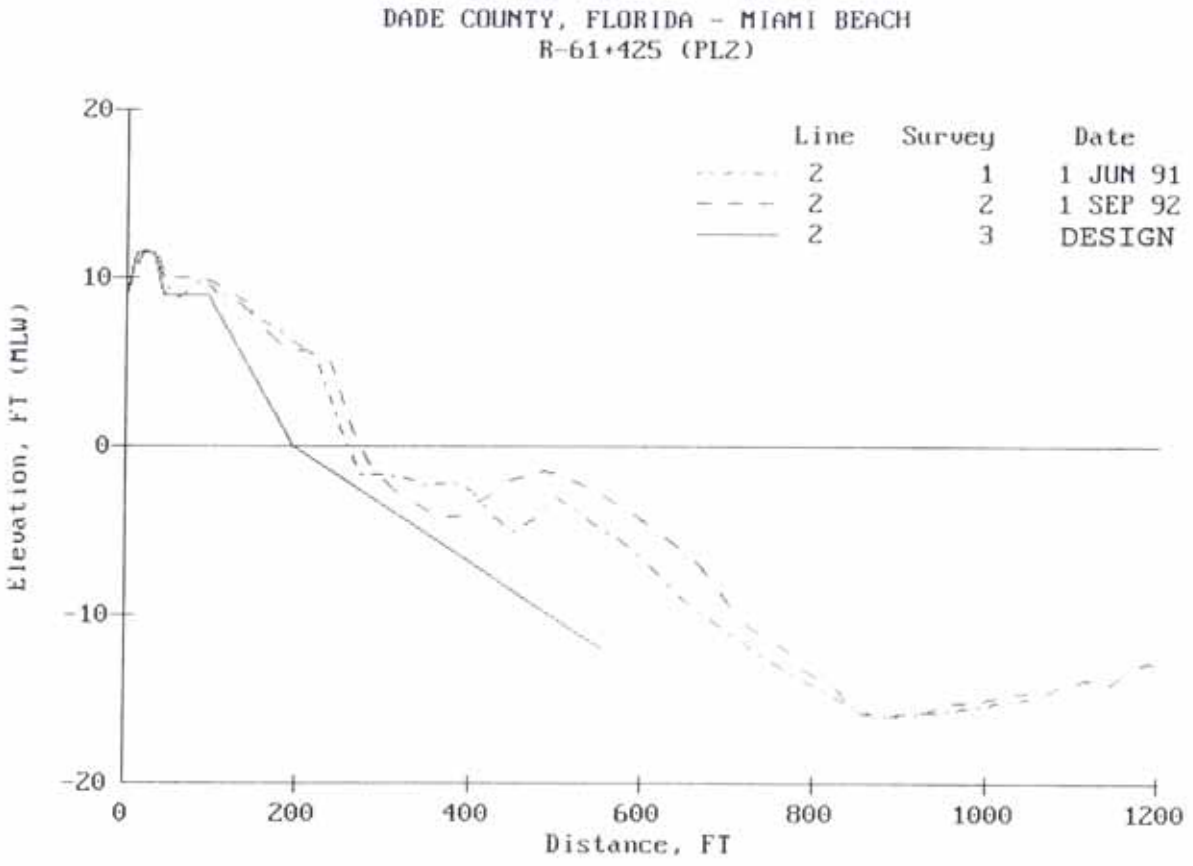
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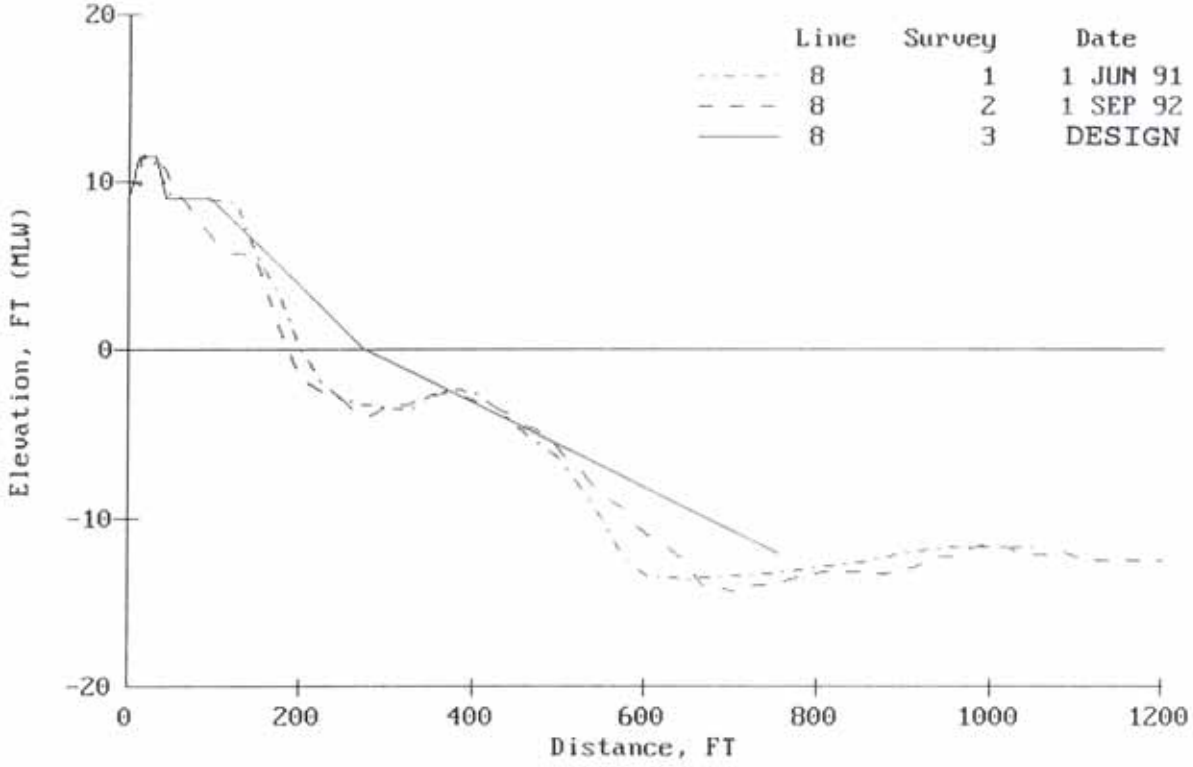

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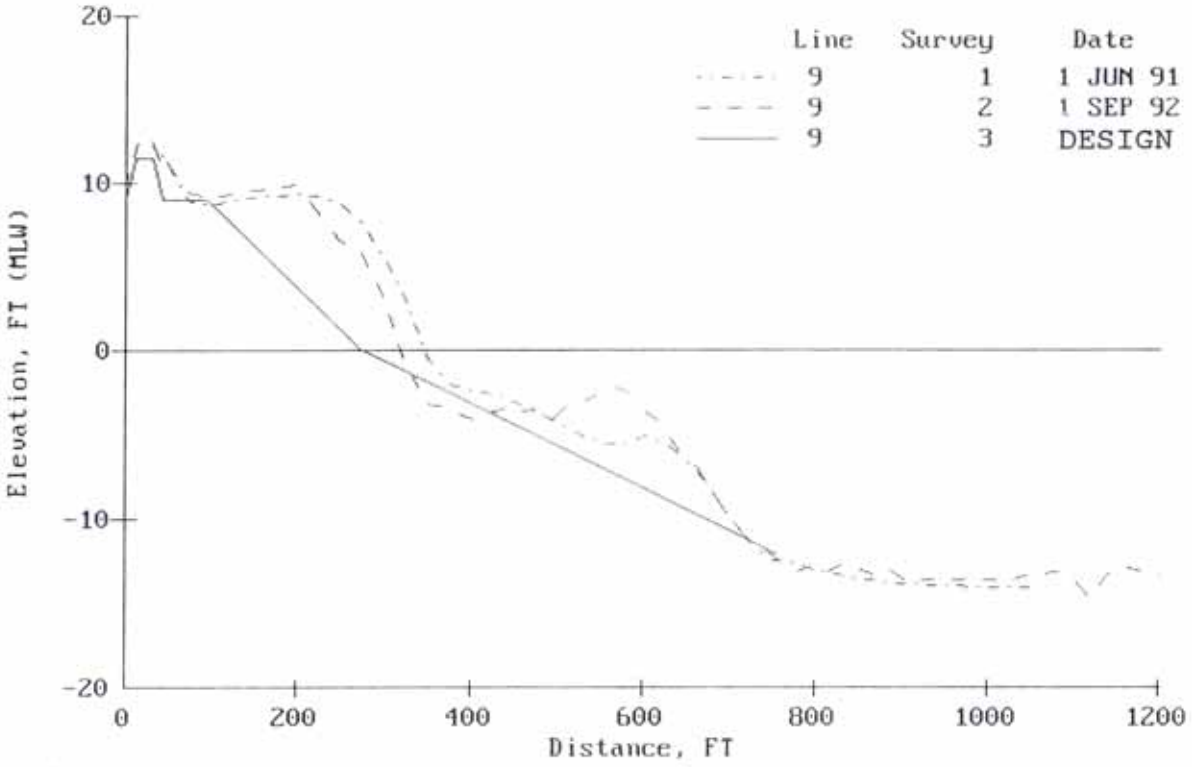

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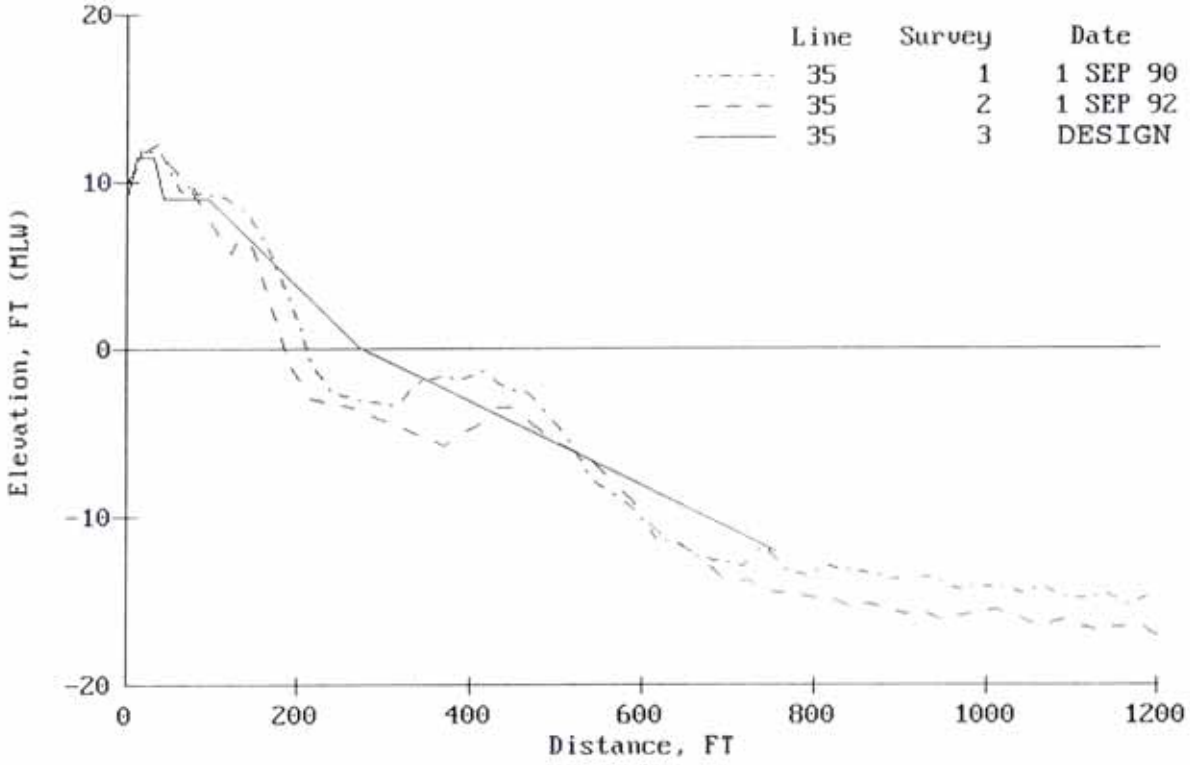

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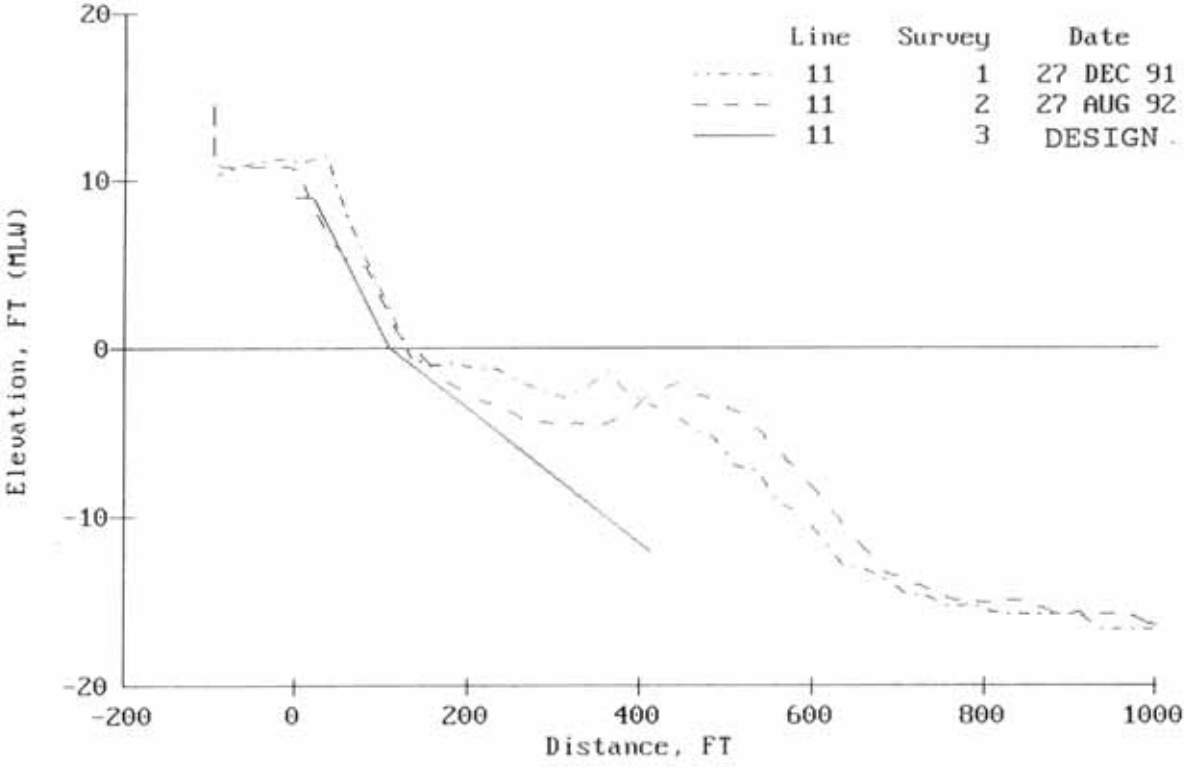

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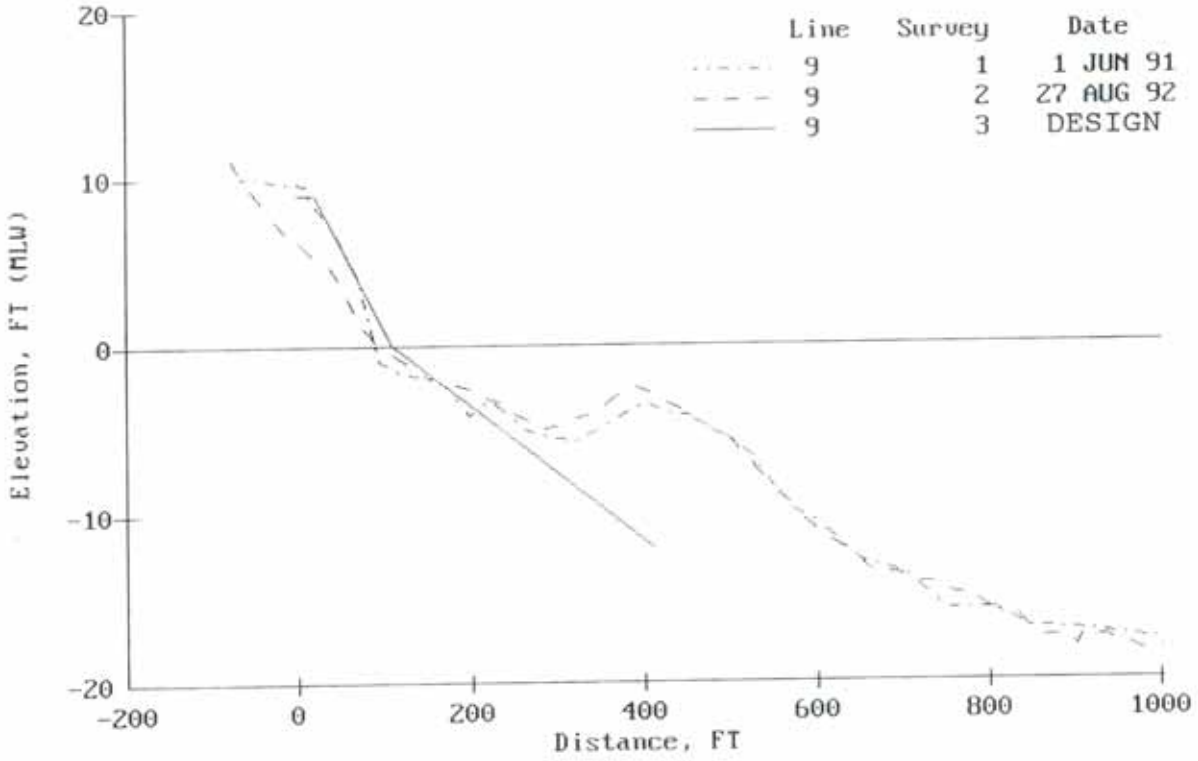

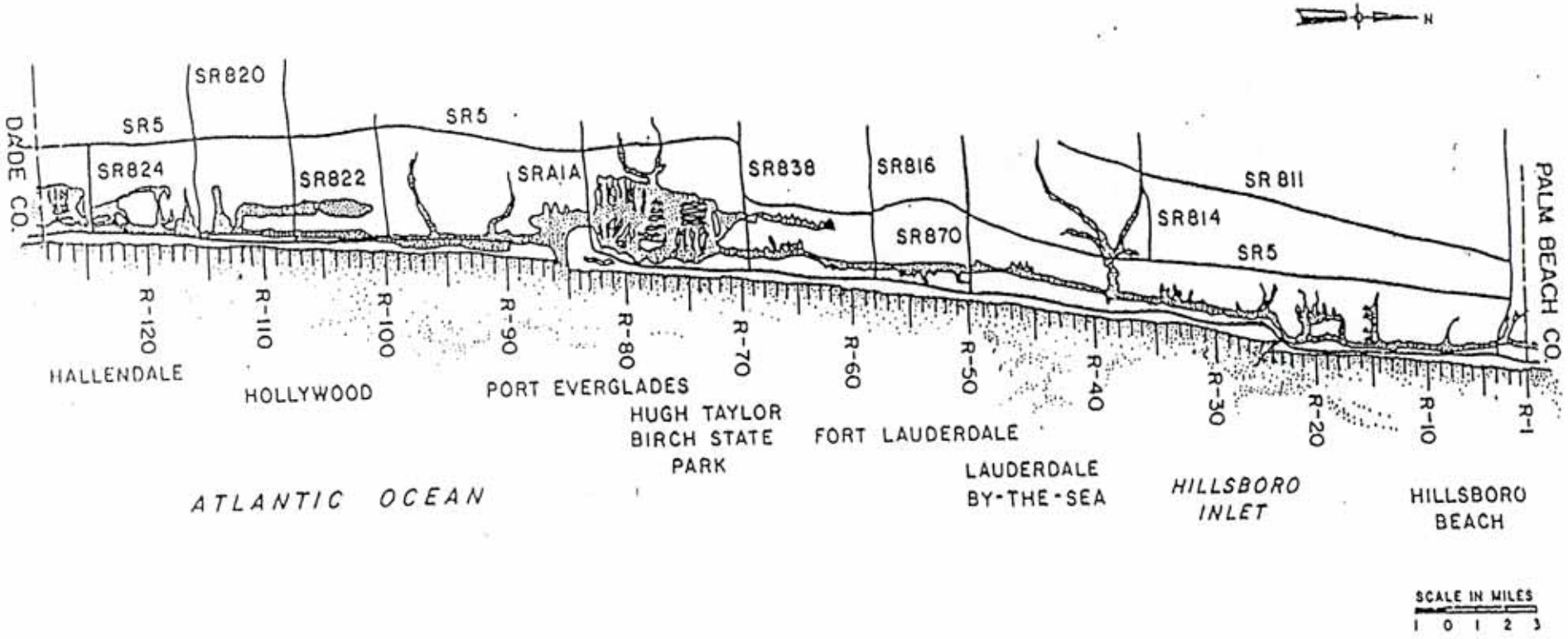

BROWARD COUNTY

BROWARD COUNTY SECMENT III HURRICANE ANDREW
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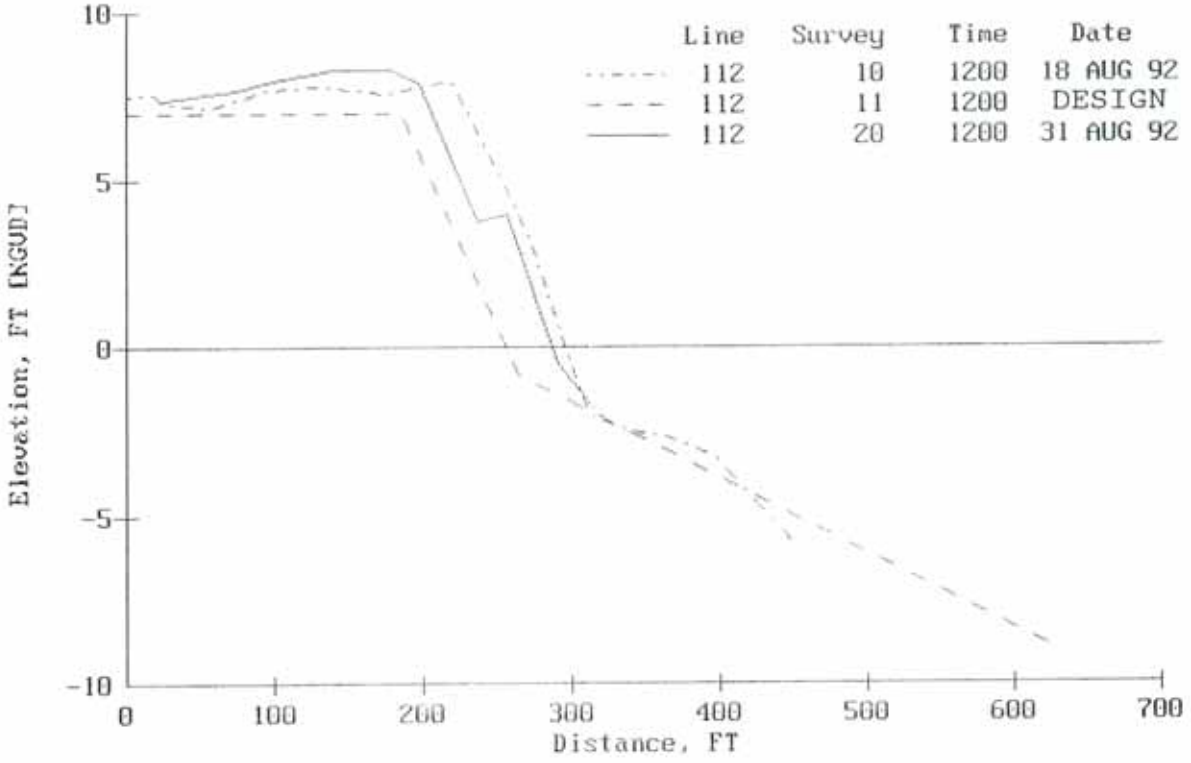

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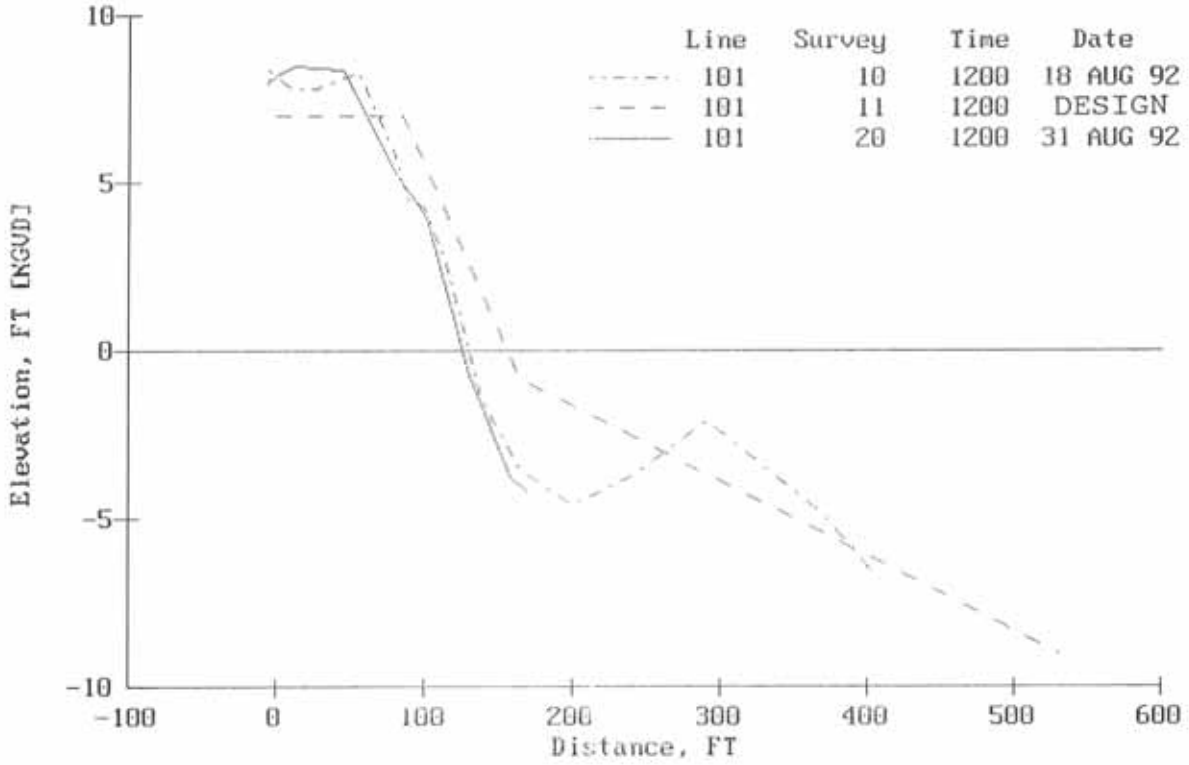
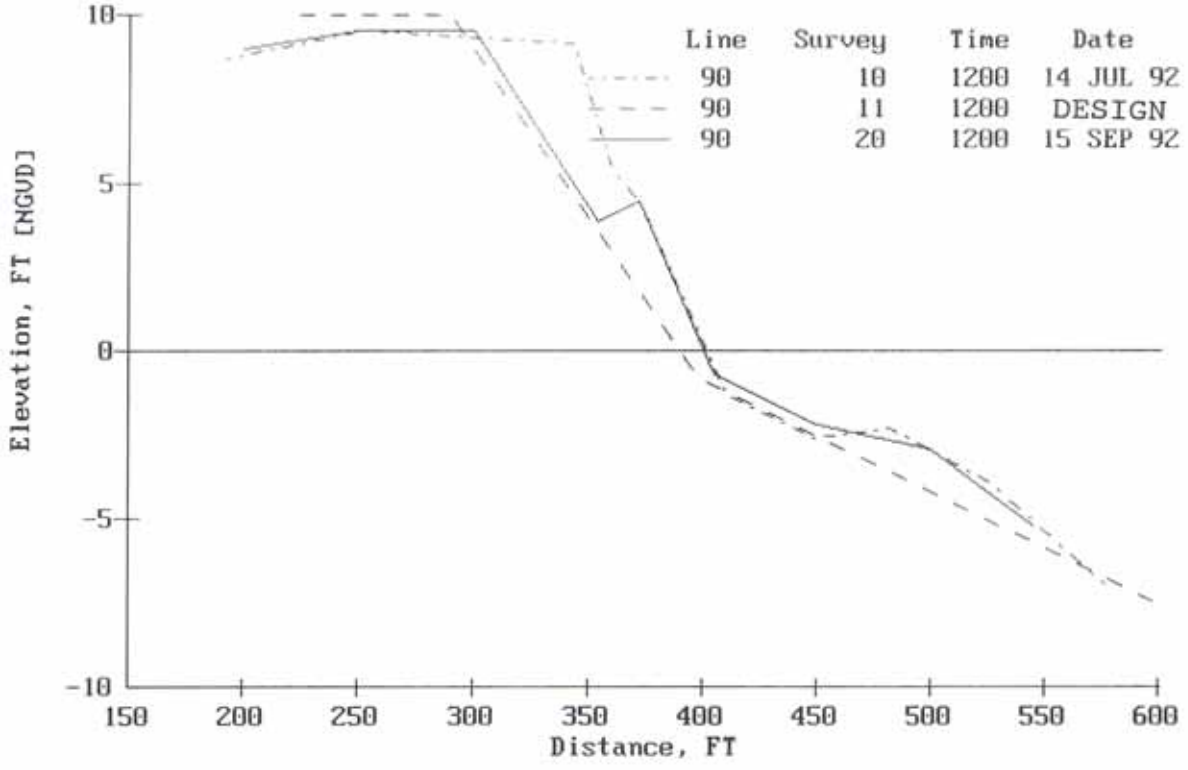
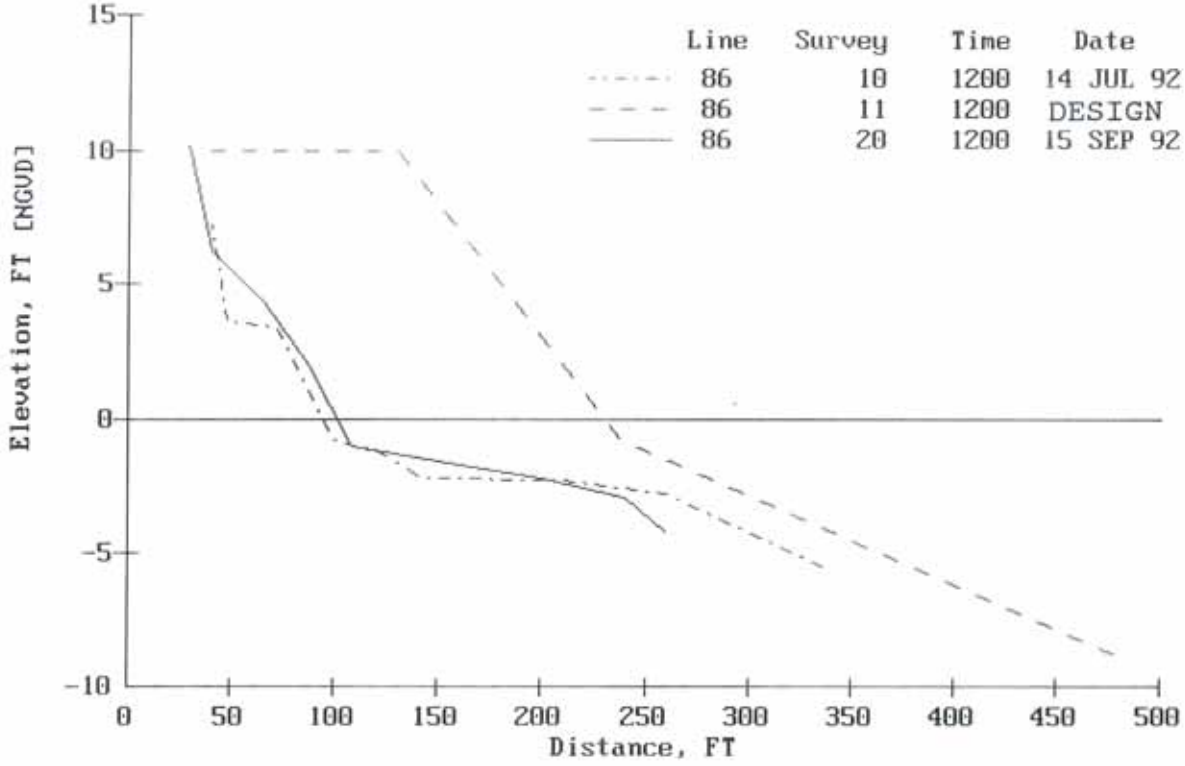


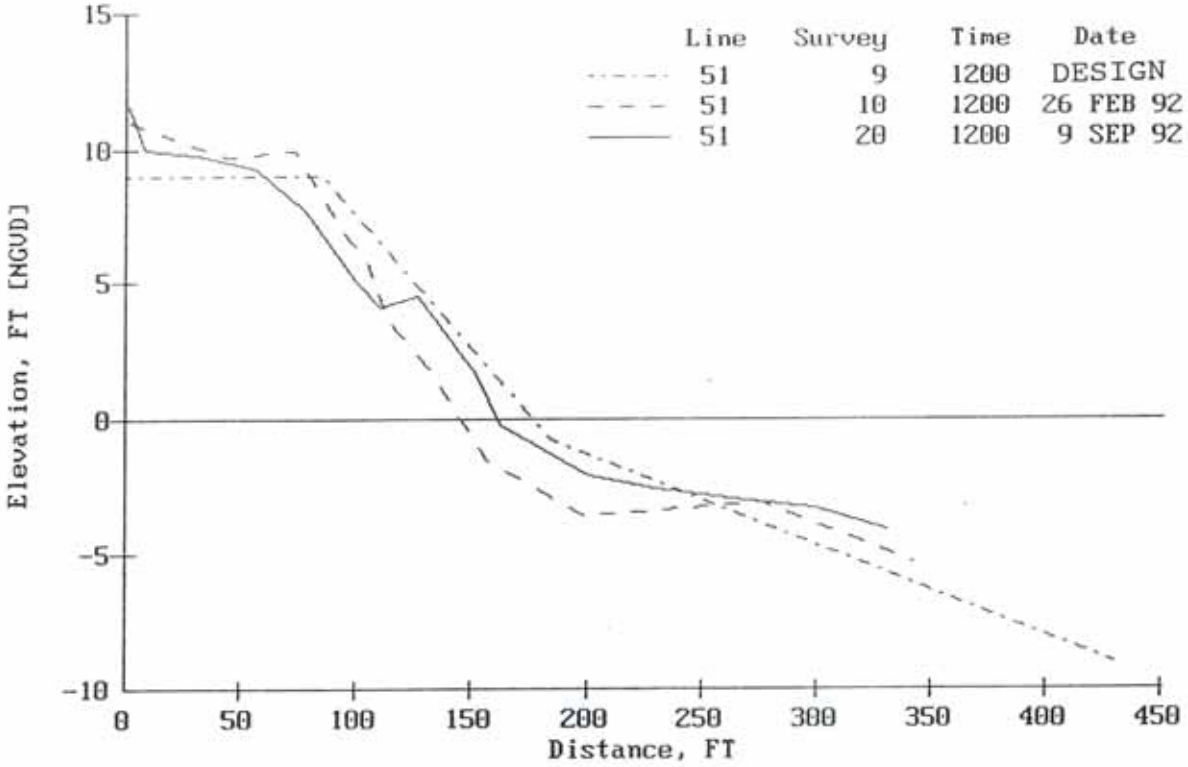
BROWARD COUNTY SEGMENT III J. U. LLOYD PARK
DESIGN TEMPLATE, PRE AND POST ANDREW SURVEYS



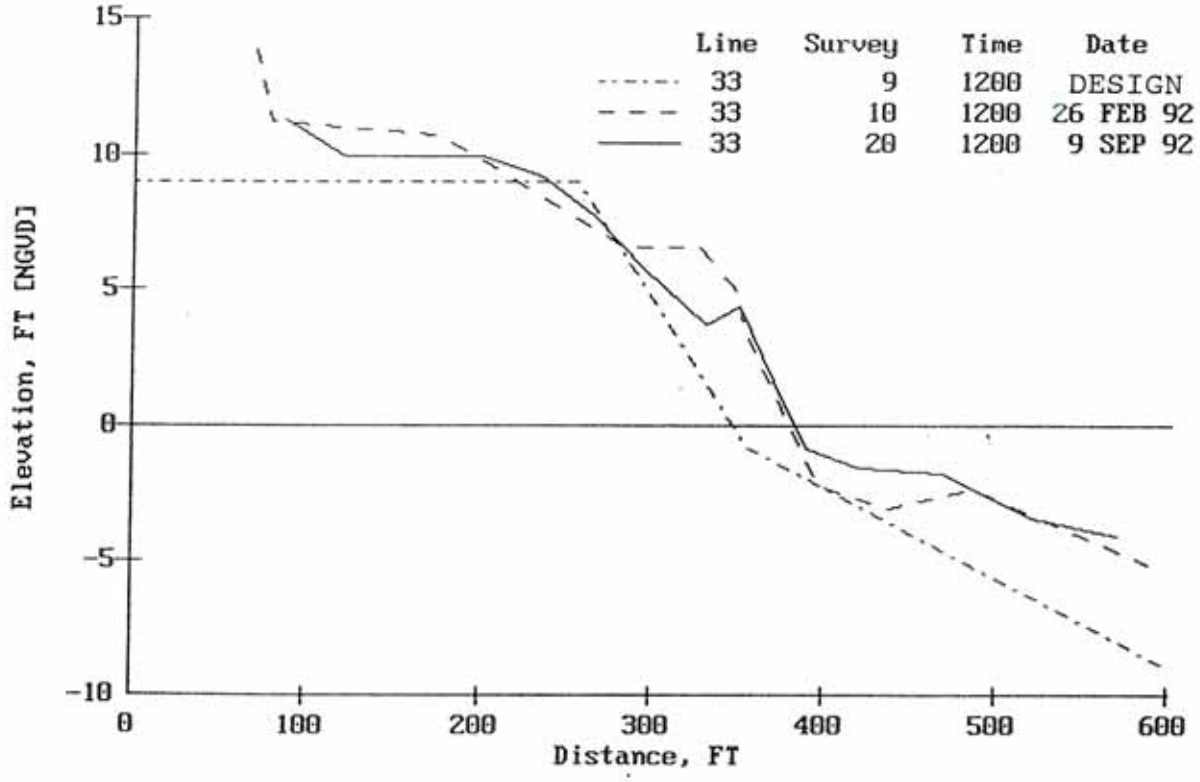
BROWARD COUNTY SEGMENT III J. U. LLOYD PARK
DESIGN TEMPLATE, PRE AND POST ANDREW SURVEYS



BROWARD COUNTY SEGMENT II HURRICANE ANDREW
PRE AND POST ANDREW W/DESIGN TEMPLATE



BROWARD COUNTY SEGMENT II HURRICANE ANDREW
PRE AND POST ANDREW W/DESIGN TEMPLATE



APPENDIX B

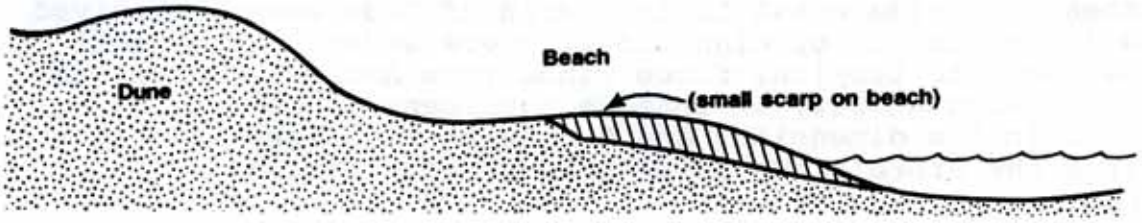
POST-STORM OBSERVATIONS OF HURRICANE ANDREW'S IMPACT ALONG THE BEACHES OF SOUTHEAST FLORIDA

Provided by:

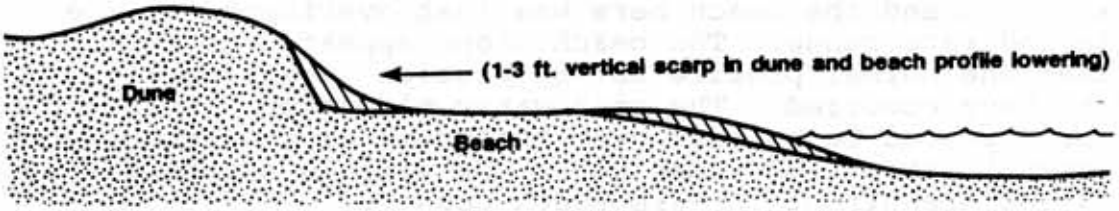
Mr. Ralph R. Clark
Florida Department of Natural Resources
Division of Beaches and Shores

BEACH AND DUNE EROSION CONDITIONS

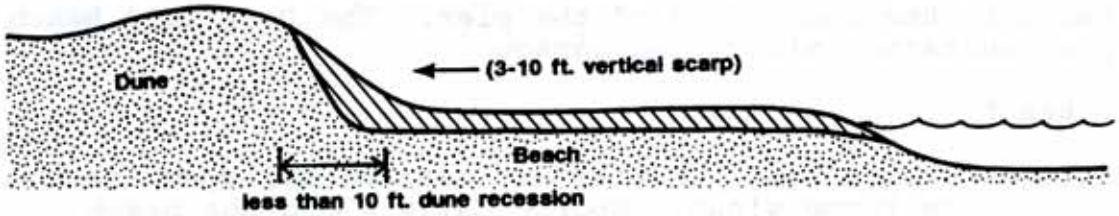
CONDITION I: MINOR BEACH EROSION



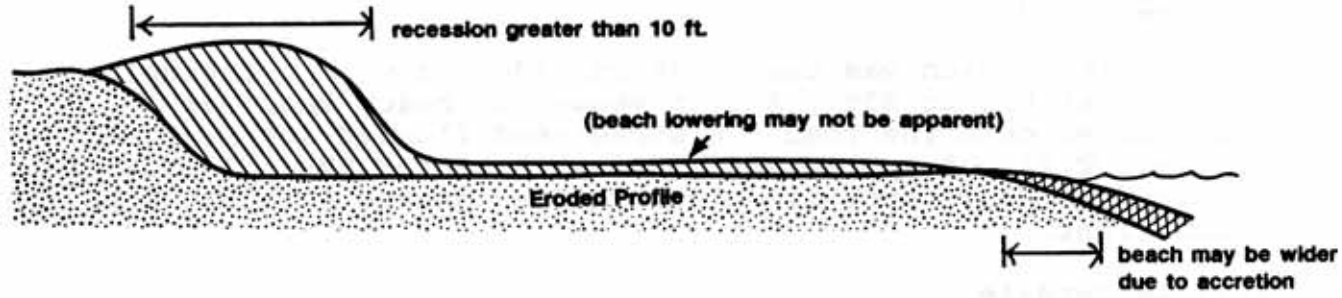
CONDITION II: MINOR DUNE AND BEACH EROSION



CONDITION III: MODERATE DUNE EROSION AND BEACH PROFILE LOWERING



CONDITION IV: MAJOR DUNE EROSION



OR:

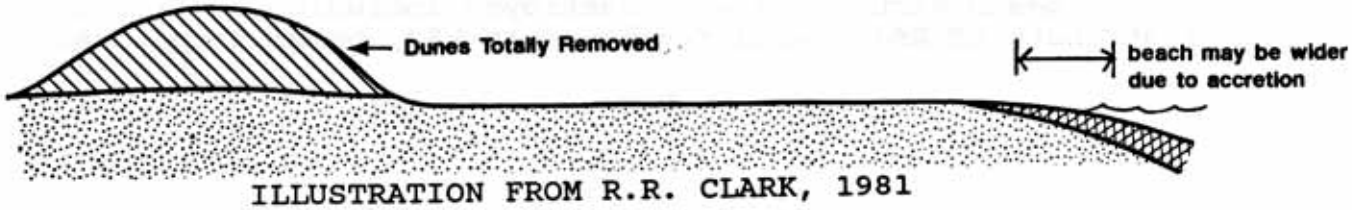


ILLUSTRATION FROM R.R. CLARK, 1981

PALM BEACH AND BROWARD COUNTIES

The southeast Florida coast to the north of Dade County received only the fringe impact of high tides, storm waves, and minimal hurricane force to tropical force winds from Andrew. Often, as was the case with Andrew, an intense hurricane is more constricted in its dimensions and the storm tide does not extend as far from the storm's eye as do that of many minimal hurricanes.

Palm Beach County

Palm Beach County was 64 miles form the geometric center of Andrew's eye. Hurricane impacts were minimal. No visible erosion was seen and the beach berm was just overtopped by the storm tide and wave runup. The beach slope appeared to be flatter than the normal profile but no erosion losses were expected to have occurred. The peak water elevation, including wave runup, appeared to be just over the crest of the south jetty at Boca Raton Inlet or +6.0 feet NGVD. No visible damage was seen along the oceanfront in Palm Beach County.

Deerfield Beach

No visible erosion was seen. Storm tide and wave overtopping occurred at R3 to R5. A thin veneer of beach sand was transported onto the road south of the pier. The Deerfield Beach fishing pier sustained minor wind damage.

Hillsboro Beach

No visible erosion was seen. A tiki hut near R8 collapsed from the tropical storm force winds. Sporadically along the beach front immediately north of Hillsboro Inlet, minor roof damage was observed.

Pompano Beach

No visible erosion was seen. Storm tide and wave overtopping occurred at R32 to R35. A thin veneer of beach sand was transported onto the road. A street-end flooded 400 feet south of R28. Tiki huts collapsed 150 feet north of R29. Flooding occurred at R29. Sporadic minor roofing damage existed along the beach front.

Fort Lauderdale

Condition II erosion (minor beach and dune erosion) was evident along the beaches of Fort Lauderdale. Along Galt Ocean Mile, some minor beach structures were destroyed including a tiki hut 300 feet south of R54, beach furniture at R57, palms toppled 600

feet south of R57, beach signs toppled and a boat grounded near R58, and a chain link fence destroyed with sand spread across a tennis court at R58. South of Galt Ocean Mile, a chain link fence was destroyed south of R59, another 100 feet of fence was destroyed 300 feet north of R60, a 100 foot concrete block ornamental wall was destroyed 350 feet south of R60, and a metal fence collapsed 100 feet south of R61. Sporadic minor roofing damage existed along Galt Ocean Mile and south of Oakland Park Boulevard to R64. A 50 foot long concrete block ornamental wall was destroyed 480 to 530 feet north of R63.

Between R64 and R78, storm tide and wave overtopping occurred. Between 6 to 12 inches of beach sand was transported onto State Road A1A. Signs and palm trees were toppled by the wave runup and scour. Numerous palms still remained standing on root balls exposed by the scour. An asphalt parking area was destroyed near R66 (approximately 100 feet shore parallel by 15 feet shore normal). An ornamental wall was destroyed at a 50-foot-wide lot west of A1A at R66 (NE 14 Court). Between R73 and R75, approximately 200 feet of ornamental wall was destroyed by wave runup. The wall was constructed of two rows of concrete masonry block, 3 to 4 blocks high, much of which had not yet been capped as part of a project which was underway. Many blocks were transported onto A1A along with beach sand.

In the block of A1A near R76, minor wind and water damage was sustained by grade level commercial buildings west of A1A. A couple of hobie cat sailboats were overturned where tied down south of R78. The rock rubble groin at R79 appears to have become more exposed by minor beach erosion. At the Marriott, about 300 feet south of R80, the sand fence was destroyed along much of the dune line.

John U. Lloyd State Recreation Area

Condition I erosion was observed along the park with a smoothed gently sloping profile. Typically, following winter storms the beach profile has a pronounced erosion escarpment; however, the storm tide and waves of Andrew apparently overtopped the berm and flattened out the profile. This is evidence that there is often more significant erosion resulting from severe winter extratropical storms which have durations lasting from a couple of tide cycles to several days as opposed to the short duration of an extreme event with higher tides. The shoreline immediately south of the Port Everglades south jetty has receded to the southeast corner of the concrete wall at R86. The shoreline position immediately prior to the storm has not yet been determined.

A significant amount of offshore debris and seaweed littered the beach throughout the park and southern Broward County. Included in the debris were offshore bottom sponges, reef fishes, sea

turtle eggs, and sea turtle hatchlings, which suggested substantial impact to the offshore reef resources as well as sea turtle nests and hatchlings on the beach. Minor roof damage was observed at the park facilities and numerous Australian Pines were downed by wind throughout the park. Heavy tree damage blocked road access to the park near T87.

Dania

No significant erosion was seen along Dania's beach. The Dania fishing pier did not appear to have sustained any major structural damage. There was beach scour seaward of the concrete ramp to the pier and sand deposits in the pier parking area from storm tide flooding. What appeared to be a minor concession structure near R100 was destroyed.

Hollywood

No significant erosion was observed along Hollywood's beaches. The storm tide and waves overtopped the beach berm and transported approximately 1 inch of sand across the Hollywood boardwalk. Several palms were toppled and a gazebo sustained major damage near T101. One tree landed on an automobile. A concrete walkway was undermined at 200 feet north of T101. Some flooding damage occurred on the lower level of a building 200 feet north of T102. A lifeguard structure sustained roofing damage near T103 landward of the beach and two lifeguard stands on the beach were tilted between R104 and R105. A chain link fence was damaged 350 feet south of R122 and a wooden concession building was blown off its slab foundation 50 feet south of R124 and deposited about 100 feet to the south in Hallandale. Sporadic minor roof and awning damage was sustained by beach front structures in Hollywood. Most grade level commercial structures along the beach front in Hollywood sustained minor flooding and sand intrusion.

Hallandale

No significant beach erosion was observed in Hallandale. The storm tide and waves overtopped the beach berm and flooded the Posner Tract at the north end of Hallandale's beach. A 100 foot fence, wood walkway and deck were destroyed 250 feet north of T126 at the Biltmore Condominium. Sporadic minor wind damages were sustained throughout the Hallandale beachfront. The Broward County/Dade County line was approximatley 38 miles from the geometric center of Andrew's eye.

DADE COUNTY: GOLDEN BEACH THROUGH VIRGINIA KEY

Dade County sustained the majority of damage from Andrew; however, northern Dade county received generally the fringe impact of this major hurricane. The storm tide along northern Dade County's beaches between Golden Beach and Virginia Key ranged between +5.1 feet NGVD and +8.8 feet NGVD. The National Water Level Measurement Network station, located at Haulover Pier adjacent to Bakers Haulover Inlet, measured Andrew's storm tide of +5.1 feet NGVD to coincide with the time of the astronomical high water.[1] This data also revealed the storm tide hydrograph to last for only one high tide phase of the semidiurnal astronomical tide.

Golden Beach

Generally only Condition I erosion was apparent along Golden Beach. This was fortunate as critical erosion conditions threaten the development in this area which, unlike Hallandale to the north and Sunny Isles to the south, has not yet received beach nourishment. Of the 68 oceanfront residences along Golden Beach, aerial videos reveal that at least 9 residences have roofing damage from the wind (see appendix A). Given the inaccuracies of aerial video surveys it is estimated that at least 20 percent of the oceanfront development sustained roofing damage. Tree and shed damage was also apparent. Overtopping caused sand deposition in pools.

Sunny Isles

The beach restoration project at Sunny Isles faired very well with only condition I to II erosion apparent after the storm. There was overtopping of the beach berm. Beach sand was pushed into the back beach and dune area and into upland properties including parking lots. At least 18 minor structures (including tiki huts, utility sheds, fences, etc.) were substantially damaged or destroyed. Of the approximately 86 oceanfront buildings, at least 20 buildings sustained roof damage and 2 other buildings sustained flood damage (Refer to Table B1). It is estimated that at least 35 percent of the oceanfront development sustained damage.

Haulover Park

Condition I erosion occurred along Haulover Park. Three lifeguard stands were damaged between R24 and R25, and major structural damage was sustained by the Haulover Pier (350 feet

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[1] Refer to Figure 11 in main report for Tide Gauge Record for August 24, 1992, Bakers Haulover Inlet.

north of R26). The pier sustained major damage during the Halloween 1991 extratropical storm and Andrew increased the damage. Two gaps now exist in the pier which also houses the tide gage for the National Water Level Measurement Network Station. Andrew's winds also caused roof damage on two concession buildings. Much of the debris from the pier was transported south and deposited on the north jetty at Bakers Haulover Inlet. Wave runup and erosion also destroyed an asphalt walkway located at the north jetty.

Bal Harbor

The beach restoration project at Bal Harbor, south of Bakers Haulover Inlet, faired very well with only Condition I erosion apparent after the storm. A substantial amount of weed/debris was observed along the beach. The concrete groins sustained minor damage from the wave activity and there was flood damage to segments of a jogging path. Although the trees and other beach vegetation faired well on the beach, numerous palm trees and seagrape were uprooted along Collins Avenue.

Surfside

The beach restoration project faired well throughout Surfside; however, there was dune overtopping at R35. A lifeguard stand was destroyed (300 feet south of R33) and a utility shed was toppled (500 feet south of R36). Aerial videos revealed roof damage to one building (400 feet north of R35); however, other oceanfront buildings probably also sustained roof damage. A cabana building 200 feet north of R35 had a section of roof ripped off.

North Shore Ocean Front Park

The beach faired well along North Shore; however, four lifeguard stands were toppled or destroyed 200 feet north of R37, 400 feet north of R39, and 400 feet north of R41.

Miami Beach

The beach restoration project along Miami Beach faired well with only Condition I erosion apparent after the storm. The barrier dune constructed for storm tide protection met its design intent with negligible overtopping. Unlike Surfside and Ft. Lauderdale, minimal sand intrusion landward of the beach occurred while much of the dune vegetation was buried by several inches of sand - a tribute to its sand trapping function. Seaward of the dune, 13 lifeguard stands were damaged or destroyed 150 feet north of R45 (stand relocated 150 feet south and toppled), near R46, near R50, near R51, 400 feet south of R51, 200 feet south of R54 at Indian Beach Park, 150 feet south of R58, 50 feet south of R67 at Lummus Park, near R68, two at 500 feet south of R68, near R69, and near R74.

In northern Miami Beach, a building sustained roof and siding damage (500 feet north of R43), a recreation building sustained roof damage (200 feet north of R43), another building had siding damage (350 feet south of R43), and a cabana building sustained roof damage (400 feet north of R45). South of Indian Beach Park, the seaward end of a dune walkover structure was damaged with the stairs gone (50 feet south of R55), a tiki hut was collapsed (400 feet south of R55), a recreation building's roof collapsed (300 feet north of R56), another recreation building's roof collapsed (300 feet north of R58), and a building's plate glass windows were blown out (100 feet north of R59). Further south at 22nd Street near R63, a condominium's pool equipment house was destroyed with the roof and a wall collapsed. Four equipment storage buildings were destroyed or substantially damaged 100 feet north of R63, near R64, 700 feet north of R65, and 400 feet north of R65. 100 feet south of R65 a portable restroom structure was damaged and moved 200 feet. At Lummus Park a boardwalk was covered with sand near R67 and trees were uprooted. Sand fencing was destroyed from R73 south to Government Cut.

Government Cut

A large amount of seaweed was attached to the north side of the south jetty. Damage to the jetties is unknown; however, the jetties appear to be completely functional with no significant rock displacement.

Fisher Island

A thick deposit of seaweed was observed along the entire beach length of Fisher Island. Condition I erosion was evident along the beach restoration area that was nourished with oolitic aragonite. Noticeable profile lowering was observed along the breakwaters and groins at R75 and R76. Groins were exposed which had previously been covered with the carbonate sediment fill. The swimming pool adjacent to the Government Cut jetty was undermined and the seaward retaining wall sustained substantial damage.

Sediment accumulation on the revetment, inland transport of revetment stone, and south end overwash 60 feet landward of the beach was reported (J.B. Manson-Hing, memorandum of September 4, 1992). Small revetment stone was transported inland up to 100 feet and several tiki huts were destroyed. Also reported by Manson-Hing was dislodged rocks from the attached breakwater structures and from the south terminal groin and groin-spur at R77. The 50-foot segment of the south terminal groin between the northward spur and the monument (R77) had its center core of sand removed leaving a hole or depression in the structure. Repair of the structure should be conducted with rock instead of sand.

The Norris Cut shoreline revetment between the terminal groin and the old Garfield estate pocket beach adjacent the marina sustained minor damage with rocks dislodged. Palms along this shoreline sustained damage. The pocket beach, marina breakwater and docks appeared to have escaped major damage as they were substantially sheltered from the southeast wind and waves.

Virginia Key

Between R84 and R79, the northern 5000 feet of Virginia Key's ocean front shoreline is stabilized by 13 large and one small rubble mound groins. This groin field appeared to hold the beach to no worse than Condition I erosion. At one localized point of erosion 300 feet north of R83, erosion appears no worse than existed before the storm. Overtopping did occur throughout, however, and surface beach sediments were transported inland. The greatest overwash appeared to be between R80 and R79 with sediments being transported into the open lagoon behind the barrier beach. Flooding occurred throughout Virginia Key and coastal damage associated with this flooding included the destruction of 700 feet of an asphalt road at R80. Also damaged in this area were lifeguard stands (500 feet south of R80, and 400 feet north of R84), picnic tables (between R80 and R81), and park signs, as well as trees and shrubs.

South of the groin field between R84 and R86 the Virginia Key shoreline had previously been described as an erosion problem area in Beaches and Shores technical and design memorandum 89-1 (Clark, 1989, 1990, 1991, and 1992). Condition II erosion and extensive flooding was apparent throughout this area. Extensive tree and shrub damage also occurred along this segment of the shoreline.

Development on Virginia Key was substantially impacted by the flooding and winds. At the north end, adjacent to and 1000 feet inland of R80, the fishing village sustained heavy damage. At least four major structures were destroyed and five others sustained major damage due to the wind and flooding which exceeded +8 feet NGVD. The Dade County sewage treatment plant also sustained minor wind and flood damage. At the south end of the island, elevated buildings on and adjacent to the Rosenstiel School of Marine Science and the Miami Seaquarium faired well but grade level minor structures sustained flood damage.

KEY BISCAYNE

Closest to the eye of hurricane Andrew, Key Biscayne sustained the most severe impact of any of the barrier beach islands of southeast Florida. Storm tide measurements between +8.8 and +9.7 feet NGVD were obtained by the Division of Beaches and Shores immediately following the storm. The island was flooded throughout from the Atlantic to Biscayne Bay, and flooding from the bay side of the island was severe. At the east dead end of the Pines Canal, the storm tide overtopped Crandon Boulevard but did not breach the island; however, the entire island was substantially under water.

Condition III erosion was sustained along the ocean front of Key Biscayne as the beach/dune profile lowered and flattened while overwash deposits revealed the conveyance of much beach sand to areas inland of the beach. The beach and dune erosion appeared to be balanced with both the extensive washover deposits and the offshore sand losses. Substantial storm tide and wave damage was sustained along the developed central portion of the island between the "bookend" parks; however, were it not for the beach restoration project, the damage would have been much greater. The now-buried concrete bulkheads would have likely been destroyed allowing for extensive erosion of the uplands along with a number of structures which were on grade level foundations. Although wave damage to development was mitigated by the restored beach, the lack of a prominent back beach dune system allowed the island to flood. This flooding was in stark contrast to the lack of flooding along Miami Beach and adjacent communities which sustained an equivalent storm tide elevation (+8.8 feet NGVD) but were protected by a barrier dune.

North Key Biscayne

Between the Bear Cut bridge (R89) and the north tip of Key Biscayne (T92) the shoreline sustained Condition III erosion. Extensive erosion and wind damage was sustained by the shoreline vegetation, which included predominantly Australian Pines, some red mangrove, and coastal shrubs. South of the Bear Cut Bridge and Crandon Boulevard extensive damage was sustained at the Crandon Marina. Numerous moored yachts sustained minor to extensive damage due to the storm tide and winds.

Between the north tip of Key Biscayne (T92) and the developed portion of Crandon Park (T95) the shoreline sustained Condition IV erosion. Extensive flooding occurred along the entirety of Key Biscayne and this area was particularly vulnerable to the wave setup driven by winds out of the northeast. The entire north end of the island appears to have been completely inundated by the storm tide of about +9.0 feet NGVD. Extensive damage was sustained by the coastal scrub and trees (particularly Australian Pines and Sabal Palms). Nearly all the damaged trees were downed in a generally southwesterly alignment.

Crandon Park

Along the developed segment of Crandon Park (T95 through R101) extensive flooding occurred. Because of the rapid rise of the storm tide and the already low beach and upland elevations, minor beach profile lowering and Condition II erosion was sustained. Thirteen lifeguard stands were destroyed or sustained extensive damage (located 500 feet north of T96, at T96, 500 feet south of T96, 100 feet north of R97, 300 feet south of R97, 250 feet north of R98, 150 feet south of R98, 400 feet north of R99, 100 feet south of R99, 400 feet north of T100, 50 feet south of T100, 400 feet north of R101, and 50 feet south of R101). A grade level building located 130 feet north of T96 and 150 feet landward of the shoreline sustained major damage to its northeast corner. Concrete slabs which served as foundations for groups of picnic tables located at R97 were undermined by localized scour. Scour around the seaward side of a circular concrete retaining wall at R98 was observed. Adjacent to T100, a pile supported wooden walkway (about 80 feet long) was lifted vertically and damaged by the storm tide. Two tiki huts were impacted near T100; one was tilted (30 feet south of T100) and one was toppled (250 feet south of T100). The deck seaward of the crescent shaped cabana building (150 feet south of T100) sustained extensive damage. Flood and roof damage was sustained by virtually all buildings within the park and extensive amounts of standing water remained throughout parking lots for days after the storm's impact. Park toll booths were toppled. Park management estimated that 90 percent of the picnic tables were destroyed or substantially damaged.

Key Biscayne - Oceanfront Private Development

Between R101 and R108, the ocean fronting private development on Key Biscayne sustained storm tide flooding and moderate wind damage. Condition III erosion was sustained throughout.

The Commodore Club East (500 feet north of R102), the Commodore Club South (200 feet north of R102), and the Islander House (R102) sustained some wind damages to apartment units but no major structural damage. A two to three foot vertical erosion escarpment remained on the low back beach dune. The Key Colony (between R102 and R103) sustained wind damages to units but no major structural damage. There was significant tree and shrub damage between R101 and R103.

Fifty feet south of R103, the Silver Sands Motel (the oldest motel on the beach built in 1956) sustained major structural damage to the seaward end of the building due to the storm tide and wave activity. The seaward units were completely gutted by the flooding, and flood damage was sustained throughout all the ground units of the building. The surrounding fence was destroyed, winds damaged windows and caused major roof damage,

and the flooding caused patio slab undermining. Ocean Drive, located 600 feet inland of the beach, remained flooded long after the storm. The Sandbar Restaurant fronting the beach (200 feet south of R103) also sustained major damage by the wind and flooding. The northeast corner of the building was destroyed. The Sonesta Beach Hotel sustained wind damage to numerous units and flooding throughout the property. After the storm the village building official had declared as unsafe 25 of the hotel's units including the entire east side of the seventh and eighth floors (15 units). The neighborhoods of single family dwellings located inland of the Sonesta Beach Hotel were hit hard by the flooding and winds. Streets such as Atlantic Road, Pacific Road, Gulf Road, and Caribbean Road remained flooded long after the storm.

Between 200 feet north of R104 and 1000 feet south of R104, the Sheraton Royal Biscayne Hotel sustained major structural damage to its ten cabana buildings. The northernmost cabana building (150 feet north of R104) was completely gutted and sustained major structural damage as its foundation slab was undermined by 2 to 3 feet of scour. The recreation building and four cabana buildings flanking the swimming pool (from 50 feet north of R104 to 200 feet south of R104) were also gutted and sustained major structural damage. Contents of all 10 cabana buildings and the recreation building were lost in the flood. An Australian Pine was uprooted and downed across the roof of one cabana building at R104 and numerous other pines and palms were uprooted around the property. Small sailboats which were moored to uprooted palms were typically destroyed.

Of the ten cabana buildings fronting the beach on the Sheraton property, four buildings were substantially destroyed (between 200 to 500 feet south of R104) and six others sustained major structural damage. Debris from these buildings was generally spread inland about 300 feet across an open area and parking lot. The main hotel buildings (from R105 to 350 feet north of R105) sustained wind damage to units and the roofs, and flooding throughout the ground level units. A 60-foot long concrete masonry block retaining wall (350 feet north of R105) was destroyed seaward of the north building and another wall bordering the swimming and wading pools was destroyed. Both pools had trapped a substantial quantity of sand. Sliding glass doors and windows were blown out throughout the property and a pool/recreation building sustained major roof and flood damage. The south building (50 feet north of R105) had its seaward ground floor units completely gutted by the storm tide. After the storm the village building official had declared as unsafe all ten cabana buildings, 46 individual hotel suites, the administrative offices, the poolside cafe and restrooms, an indoor restaurant and the grand ballroom.

At the Sands Condominium (R105 to 300 feet south of R105) most of the seaward units sustained significant wind damage. A metal fence along the north half of the seaward property line was destroyed and the property was flooded throughout. At the Sands Condominium and elsewhere throughout the island heavy wind damage was sustained by parked automobiles. To the south of the Sands Condominium, the Key Biscayne Beach Club (400 feet south of R105) sustained major flood and roof damage. Completely gutted by the storm tide was the recreation club building and the Beach Basket restaurant. Tiki huts were destroyed along with vegetation. The storm tide overwash left a substantial quantity of sand inland of the beach.

Extending from 500 feet north to about 600 feet south of R106 is the generally vacant property which was once occupied by the Key Biscayne Hotel. On the northeast corner of the property are ten grade level two-story buildings including three which fronted the beach. All ten structures were gutted by the flooding and the seaward three structures sustained major damage inflicted by the wind and waves. Major roof damage was also sustained by these structures. About 300 feet to the south (generally from R106 to 200 feet south of R106) are three more of these grade level two-story buildings which shared the same fate, being flooded and sustaining major damage from the wind and waves. A reinforced concrete bulkhead exists along the 1100-foot beach frontage but it did not show signs of major damage. In this case the wall did not sustain major damage due to the low cap elevation which just tops the beach grade and the fact that the storm tide inundated the wall by several feet thereby reducing scour effects to a minimum. The chain link security fence on top of the wall was completely destroyed and was carried inland across the property by flood waters. As the fence was pushed inland it scraped up all low shrubs and other vegetation in its path. It is highly probable that had all the past development still existed on the property the damages on this property alone would have been catastrophic.

The southernmost group of multistory condominiums fronting the beach sustained major wind and flood damage. The Casa del Mar (350 feet to 50 feet south of R107), the Mar Azul (R107 to 300 feet south of R107),and the Towers of Key Biscayne (400 feet to 800 feet south of R107) sustained major wind damage to many units and flooding throughout the properties. Swimming pools were flooded and recreation decks and gazebos were damaged. Numerous vehicles on the upper parking deck of Casa del Mar were blown around with some flipped over and some left resting on top of other vehicles resulting in a scene more typical of a demolition derby. At ground level, a sheet of sand covered the pool deck, and the pool served as a settling basin for beach sand bed load carried by the flood waters. The metal pool fence was completely destroyed and the ground floor units of both two-story buildings seaward of the highrise structure had their ground floor units

flooded. After the storm, the village building official had declared as unsafe eleven of the units of the Casa del Mar and had also cited the lobby as having been damaged.

At the Mar Azul a similar sand sheet was transported in across the property, the seaward metal fence was destroyed, and the pool was flooded and had entrapped a substantial quantity of beach sand. Major structural damage was sustained along the floor level of the top story of the building where it appears that uplift pressures on the roof and ceiling caused the building to break away. Substantial roof damage was also sustained by the grade level room adjacent to the pool. Substantial damage was also sustained by the ornamental shrubs and trees throughout these properties. A number of shrubs were even left deposited in the Mar Azul's pool. After the storm, the village building official had declared as unsafe four of the units including the penthouse ballroom.

Automobiles left parked on the grade level parking lots of these properties were also substantially damaged by the wind and flooding. One vehicle in the Towers lot was found burnt by a fire which appeared to have erupted internally because no power line was present. However, some of the worst automobile damage was sustained in the substructure parking garage of the Towers. Poststorm water marks indicate that any entrapped vehicles which floated would have been battered from above and below as well as by walls, columns and other vehicles. Several vehicles were transported out the south side of the parking garage by the flood tide driven current. The 3 to 4-foot deep tide gully channeled the storm waters across the beach 400 feet south of R107 as the storm tide fell and water was released from an underground exit to the parking garage. A scour hole in the asphalt parking area and a 3-foot deep deposit of sand left entrapped in the under-structure parking garage along with other floating shrubs and debris, indicated that a substantial storm tide flood current was conveyed into and through the Towers' subgrade parking garage. The flood tide's overtopping of Crandon Boulevard at the southwest corner of the property and into Pines Canal allowed sufficient flow through the garage to convey a significant sediment load.

Wind damage was sustained throughout the Towers property and the buildings had many windows, shutters, and doors blown out, rails removed, and apartment interiors gutted. The east building had 25 units declared as unsafe after the storm by the village building official. At the southeast corner of the Towers property, all the recreation decks and facilities were substantially damaged or destroyed. Walkways, decks, rails, and shrubbery were impacted by the storm tide and wind. The roof of the gazebo was blown off and left deposited "topside up" about 30 feet to the southwest. The chain link fence bordering the state park to the south had about 50 feet of its seaward end destroyed

and another security fence was destroyed near the gazebo by a few small sailboats which were piled up in the storm's flood tide. The south subgrade parking area of the Towers provided a flume for storm tide flooding to be conveyed between the beach and the east end of the Pines Canal. Vehicles left piled up in the southwest corner and the south shoulder washout of Crandon Boulevard by the state park entrance indicate flood waters were conveyed across this 850-foot ocean-to-bay flume.

Inland of the ocean front were other significant damages. On Ocean Drive, the building official declared as unsafe 19 units of the Bahia Mar condominium and nine units of the Ocean Drive Manor. Along Crandon Boulevard, declared as unsafe were eight units of the Key Biscayne Ambassador, one unit of the Crandon Tower, three units of the Key Colony Ocean Sound, two units of the Key Colony Tide Mark, 11 units of the Key Colony Emerald, six units of the Key Colony Botanica, two office suites in the Arcade Shopping Center, one office suite in the Key Biscayne Shopping Plaza (the Keys Real Estate Office), and two office suites at the L'Esplanade. On Sunrise, declared as unsafe were three units of the Sunrise Manor, the penthouse east of 155 Sunrise, and four units of the Governor's Lodge. Also declared as unsafe were three units of Cape Florida II on Seaview, seven units of Ocean Plaza on Ocean Lane, and eight units of the Galen Breakers on Galen. Elsewhere on the island four single family residences were declared unsafe on Woodcrest Road, North Mashta, Harbor Lane, and Allendale Road.

Cape Florida

At no other location on the barrier islands of southeast Florida was there witnessed damage as severe as that observed on the south end of Key Biscayne at Bill Baggs Cape Florida State Recreation Area. The once-dense forest of Australian Pines was flattened. Over 95 percent of the park's trees including palms were toppled by the wind. The poststorm debris removal involved an estimated 490,000 cubic yards of trees, limbs, and stumps.

The beach and dune system was leveled to a very gradual slope and the six elevated beach/dune walkover structures were substantially destroyed. The Cape Florida lighthouse, the oldest standing structure in Dade County, survived another test of wind and water. The concrete bulkhead fronting the lighthouse was overtopped and minor scour was sustained as water was conveyed laterally behind the wall. The terminal rock groin which anchors the south end of the beach provided a breakwater to the wave activity which would have threatened the bulkhead. The storm tide appeared slightly lower at the south end of the island in comparison to the central area where greater wind and wave setup should have occurred. Damages to park facilities are summarized in Table B2.

TABLE B1

Golden Beach (68 oceanfront residences)

200' N R3 damage shed on beach side of wall
R3 to N house roofing
50'S R3 house roofing
500'S R3 house roofing
R4 Recreational Building house roofing and tiki hut
350'N R5 house roofing
300'N R5 house roofing
R5-5 house roofing
250'S R5 house roofing
450'S R5 house roofing
350'N R7 house roofing
100'N R7 palms down

Sunny Isles (86 oceanfront buildings)

600'N to R8 chain link fence condition II erosion
R8 Tiki hut toppled
250'S R8 slab? shuffleboard court?
275'N R9 utility shed roofing
200'N R9 building roofing
R9 building roofing
150'S and 250'S R9 sand in parking lots
300'S R9 building roofing
500'S to 700'S R9 4 tikis down
500'S to 500'S R9 windows damaged
900'S R9 tiki down
500'N R10 (1000's R9) tiki down
350'N R10 tiki down sand in parking lot
200' - 400'S R10 beach lounge chairs transported landward
350'N R11 building roofing
250'N R11 property flooded
150'N R11 building roofing
600' - 250N R12 ornamental fence destroyed
350'N R12 building roofing
150'N R13 building roofing
75'N R13 building roofing
150'S R13 tiki down
250'S R13 building roofing
350'N R14 tiki down
150'N R14 building roofing
50'N R14 building roofing
80'S R14 tiki hut collapsed
400'S R14 building roofing
100'S R15 building roofing, fence destroyed, 1st floor rooms flooded and damaged
250'S R15 pool flooded
350'S R15 building roofing, fence destroyed, 1st floor rooms flooded and damaged
450'S R15 building roofing and 3 tiki huts collapsed or toppled

TABLE B1 (CONT'D.)

600'S R15 building roofing
650'S R15 building roofing
350'N R18 building roofing
450'S R18 building roofing
500'S - 750'S R18 building roofing and window damage

TABLE B2. Damage at Bill Baggs Cape Florida State Park (from Damage Survey Reports, Federal Emergency Management Agency)

Damaged Facility	Nature of Damage
Entrance Station Building	Minor Roof
Entrance Booth Building	Minor Roof & Sliding Glass Door
Park Office Building	Roof & Ceiling
Park Manager's Residence	Ceiling
Asst. Park Managers Residence	Ceiling, Carpet, Window Awnings, Truss, & Deck
Mobile Home	Roof, Ceiling, Carpet, Subfloor, & Floor
Cape Florida Lighthouse	Lantern Room Lights & Tower Masonry (18cy of fill)
Lightkeepers House	Roof & Doors
Lighthouse Kitchen	Roof
Bahama House	Ceiling Fans & Doors
Metal Utility Building	Roof & Door
Shop & Storage Building	Roof, Siding, Framing, Doors & Windows
Concession Building	Roof
Restroom Building No. 1	Roof, Skylight, Interior debris removal
Restroom Building No. 1 1/2	Roof, Skylight, Interior debris removal
Restroom Building No. 2	Roof
Restroom Building No. 2 1/2	Roof, Decking & Truss, Roof, Skylight, Interior Debris Removal
Restroom Building No. 3	Roof
Restroom Building No. 4	Roof, Roof Decking
Restroom Building No. 5	Minor Roof
Restroom Building	Minor Roof, Privacy Screen
Restroom Building	Siding, Framing, Roof, Rafters & Sheathing, Privacy Screen, Plumbing
Swing Set	2 Destroyed
Wooden Beach Access Walkways	1200 Feet Destroyed
Palm Trees	Replant 17
Wooden Picnic Tables	125 Damaged
Trash Barrels	30 Damaged
Bulkhead	Lost 96 cubic yards of back-fill & 52 cubic yards of riprap
Fence	1033 feet damaged

UPPER FLORIDA KEYS

The geometric center of Andrew's eye crossed Elliot Key located in the northernmost Florida Keys. The south Florida island chain known as the Florida Keys is an elongate, arcuate archipelago over 220 miles in length from the tiny Soldier Key at the northeast end of the chain about four miles south of Key Biscayne to the Dry Tortugas located well into the Gulf of Mexico. Elliott Key is over six miles in length and is part of the Biscayne National Park.

Beach and dune formation in the Keys is not common, and compared to the barrier beaches north of Cape Florida there is very little quartz sand on the Keys. Most of the upper Keys shoreline is rock; however, the undeveloped Elliott Key has numerous small pocket beaches of carbonate material perched over the bedrock of the Key Largo limestone formation. These beaches are as yet largely unstudied and data on their shoreline processes are not available.

Both erosion and accretion was apparent following the impact of Andrew; however, large fluctuations in the shoreline was not in evidence because of the geological control over the shoreline position. The sand of these northern Keys pocket beaches is of carbonate origin derived substantially form the erosion of exposed limestone rock, and from the fragmented remains of corals, cast-off shells, and calcareous algae. The rising and falling storm tide and the turbulence of the storm wave activity transported sediments from the region between the island and the barrier reef (Hawk Channel) shoreward and onto the island as well as toward the offshore.

The storm tide was measured near the north end of Elliott Key although the one dwelling which did exist near the north end of the island was completely destroyed with only some remnants of the foundation remaining. Heavy damage to native vegetation occurred throughout Elliot Key and the undeveloped Sands Key to the north. On the small Boca Chita Key north of Sands Key, the few structures were substantially damaged by the flooding and the winds. The thick coral rock walls of one large structure survived but the roof was blown off and the interior was gutted by the wind and the flooding.

To the north of Sands Key and also in the eye of Andrew were the narrow Ragged Keys. Substantially undeveloped, these small privately owned islands were denuded of most of their vegetation. Development on Ragged Key Number 3 sustained heavy damage and amazingly and inhabitant survived the storm there notwithstanding flooding to the second floor of his roofless dwelling.

Three miles north of the Ragged Keys and four miles south of Key Biscayne is Soldier Key which was in the eye wall of Andrew subjecting it to the highest winds and tides. The sole structure and much of the vegetation on Soldier Key was destroyed.

South of Elliott Key and the geometric center of Andrew's eye, the undeveloped islands of Old Rhodes Key, Totten Key, Swan Key, Palo Alto Key, and Angelfish Key, all sustained substantial damage to their predominantly native trees and shrubs. On northern Key Largo within Monroe County substantial wind damage also occurred to both the vegetation and the private residential development at the Ocean Reef Club. Flooding was not as severe in this area because, although the ground elevations are low, the storm tide was only a few feet above normal. No erosion was apparent along the oceanfront shoreline of Key Largo because the exposed Key Largo limestone formation in this area is without natural sandy beaches. An artificially created perched beach at the Ocean Reef Club did not appear to have been significantly impacted.