1

Introduction

On August 19, 2004, the Federal Emergency Management Agency's (FEMA's) Mitigation Division deployed a Mitigation Assessment Team (MAT) to Florida to assess damages caused by Hurricane Charley. This report presents the MAT's observations, conclusions, and recommendations in response to those field investigations.

Chapter 1 provides an introduction, a discussion of the event, historical information, and background on the MAT process. Chapter 2 presents a discussion on the codes, standards, and regulations that affect construction in Florida. Chapters 3 through 5 provide a characterization and discussion of the observed damages to residential, commercial, and critical/essential buildings from Hurricane Charley. Chapter 6 presents observations regarding damages and loss of function to critical and essential facilities in the counties impacted by the hurricane. Chapters 7 and 8 provide the conclusions and recommendations, respectively, that are intended to help guide the reconstruction of hurricane-resistant communities in Florida and all hurricane-prone regions. Chapter 7 also contains examples of mitigation successes. Additional information related to the specific technical issues is presented in the appendices. Appendix A contains the references for the report, and Appendix B is a list of acknowledgments. Appendix C defines the acronyms and abbreviations used in the report. Appendix D contains FEMA *Hurricane Recovery Advisories No.1 (Roof Underlayment for Asphalt Shingle Roofs), No. 2 (Asphalt Shingle Roofing for High-Wind Regions)*, and *No. 3 (Tile Roofing for Hurricane-Prone Areas)*. Appendix E provides information on the history of hurricanes in southwest Florida.

Appendix F contains guidance and statute requirements for design and construction of Enhanced Hurricane Protection Areas (EHPAs) from Florida's State Emergency Shelter Program (SESP).

Hurricane Charley was categorized as a Category 4 hurricane on the Saffir-Simpson Hurricane Scale by the National Hurricane Center (NHC) in its *Tropical Cyclone Report, Hurricane Charley, 9-14 August 2004* (NHC, October 2004), with 150 miles per hour (mph) estimated 1-minute sustained wind speeds (over open water). As the storm made landfall on the barrier island of North Captiva, surface winds could not be measured, but best available data indicate wind speeds were at or below this wind speed. On the east side of Charlotte Harbor, the MAT estimated the hurricane struck the Port Charlotte/Punta Gorda area as a strong Category 3 or borderline Category 4 hurricane with 1-minute sustained winds of approximately 125 mph to 130 mph, and maximum 3-second peak gust winds of 155 mph to 165 mph. Because of the limited amount of surface data and frequent failures of instruments, a significant amount of uncertainty surrounds wind speed estimates at specific locations and information about the storm's winds is still being analyzed by various modelers. However, there is reasonable agreement on the maximum wind speeds at landfall. The wind and flood data included herein reflect the best available estimates at the time of release of this report.

Hurricanes are classified into different categories according to the Saffir-Simpson Hurricane Scale. Table 1-1 gives the categories of the Saffir-Simpson Hurricane Scale along with their respective wind speeds, presented as 1-minute sustained wind speeds and as 3-second peak gust wind speeds, as well as their respective wind pressures. A "major hurricane" is a term utilized by the NHC for hurricanes that

Table 1-1. Wind Speeds of the Saffir-Simpson Hurricane Scale

Strength	Sustained Wind Speed (mph)*	Gust Wind Speed (mph)**	Pressure (millibars)
Category 1	74 – 95	90 – 119	>980
Category 2	96 – 110	120 – 139	965 – 979
Category 3	111 – 130	140 – 164	945 – 964
Category 4	131 – 155	165 – 194	920 – 944
Category 5	>155	>194	<920

* 1-minute sustained over open water ** 3-second peak gust over open water

reach maximum 1-minute sustained surface winds over open water of at least 111 mph (96 knots), the threshold velocity for a Category 3 hurricane. A more complete discussion of preliminary wind speed estimates based on surface wind measurements and computer modeling is provided in Section 1.2.

1.1 Hurricane Charley – The Event

According to the NHC, on August 10, 2004, Hurricane Charley developed from a tropical depression to a tropical storm. Charley was upgraded from a tropical storm to a hurricane on August 11, and tracked west-northwest across the Caribbean, impacting Jamaica and Cuba. This report will discuss and present observations of the damage along the path in some of the hardest impacted areas of Captiva and North Captiva Islands, and the cities of Port Charlotte, Punta Gorda, and Arcadia.

1.1.1 Summary of Winds

The National Weather Service (NWS) and the NHC reported Hurricane Charley made landfall on the Gulf Coast of Florida on Friday, August 13, 2004, just before 4:00 p.m. (Eastern Daylight Time, EDT) when the center of Charley crossed the barrier islands of Cayo Costa and Gasparilla at 3:45 p.m. as a Category 4 hurricane with estimated winds of 150 mph (1-minute sustained over open water) (NHC, October 2004). After crossing the barrier islands, Charley moved up Charlotte Harbor before striking Mangrove Point, just southwest of Punta Gorda, at 4:35 p.m. By 5:30 p.m., the center was 5 miles west of Arcadia (De Soto County) and, at 7:30 p.m., was 4 miles west of Lake Wales (Polk County). At approximately 9:15 p.m., the storm hit the Orlando International Airport. By 11:30 p.m., the hurricane was back over open water, having exited the Florida peninsula near Daytona Beach. By 2:00 a.m. EDT, the center was over the Atlantic about 45 miles north-northeast of Daytona Beach, with maximum sustained winds reported to be 85 mph (1-minute sustained over open water) after having moved across Florida with an average forward translation speed of near 20 mph. Figure 1-1 is an infrared satellite image of Hurricane Charley just prior to landfall.

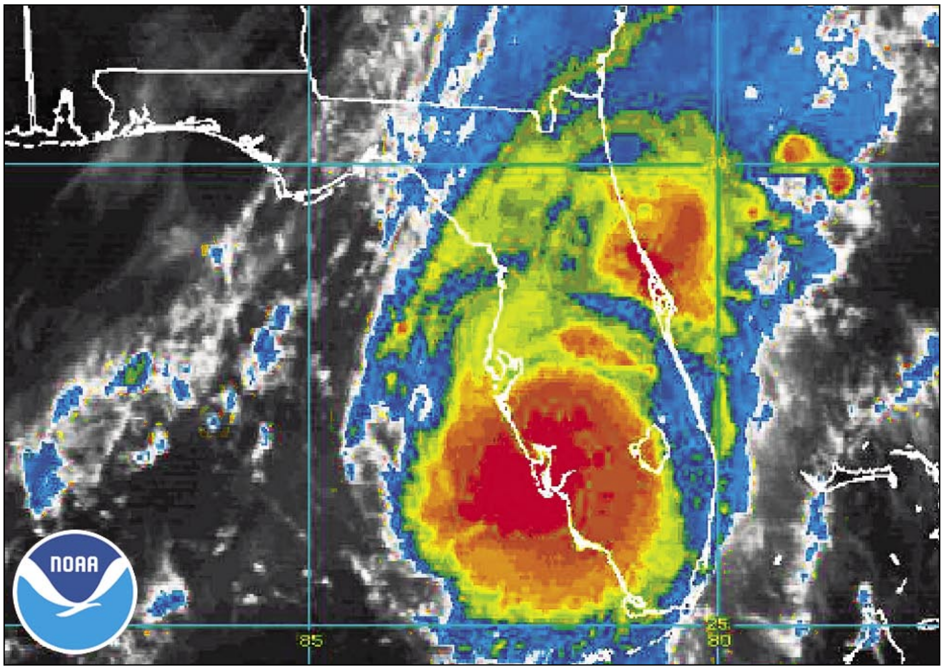


Figure 1-1.
Infrared satellite image of Hurricane Charley making landfall on the southwest Florida coast on August 13, 2004

(NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION [NOAA])

Very few wind speed measurements were obtained for Charley that reflected the actual strength of the storm as it made landfall and moved across Florida. This was due to the small number of weather stations near the point of landfall and the variable performance of stations remaining on-line and recording data during the hurricane. All wind speed data were obtained from the measuring stations and confirmed in the October 2004 NHC report unless otherwise noted. Notable wind speeds recorded and verified from Hurricane Charley were obtained at the following locations:

- Around the time of landfall:
  - 112 mph (3-second peak gust) in Punta Gorda (with a 87-mph, 2-minute sustained wind speed)*
  - 87 mph (3-second peak gust) at the Cape Coral Airport (SOURCE: FLORIDA COASTAL MONITORING PROGRAM [FCMP])

(*Note: NWS reported that the anemometer used to measure wind speeds stopped recording just before the height of the storm at Punta Gorda, NHC, October 2004.)

- Over land, before exiting into the Atlantic Ocean:
  - 105 mph (3-second peak gust) at the Orlando International Airport**
  - 92 mph (3-second peak gust) at the Sanford Airport just northeast of Orlando**

- 83 mph (3-second peak gust) at the Daytona Beach Airport (with a 69-mph, 1-minute sustained wind speed)**
- 87 mph (3-second peak gust) at Ormond Beach (with a 68-mph, 1-minute sustained wind speed)**

(**Note: NWS reported that the anemometer used to measure wind speeds stopped recording before the height of the storm at the Orlando International and Sanford Airports, NHC, October 2004.)

Figure 1-2 shows the approximate extent of tropical storm winds (39- to 73-mph, 1-minute sustained wind speed) and hurricane force winds (greater than 74-mph, 1-minute sustained wind speed) for Hurricane Charley. These wind contours are based on a combination of actual wind readings and meteorological data evaluated by the NOAA H-wind model shortly after Charley made landfall. Additional information regarding the wind field and gradation of winds along the path of the hurricane are presented in Section 1.2.

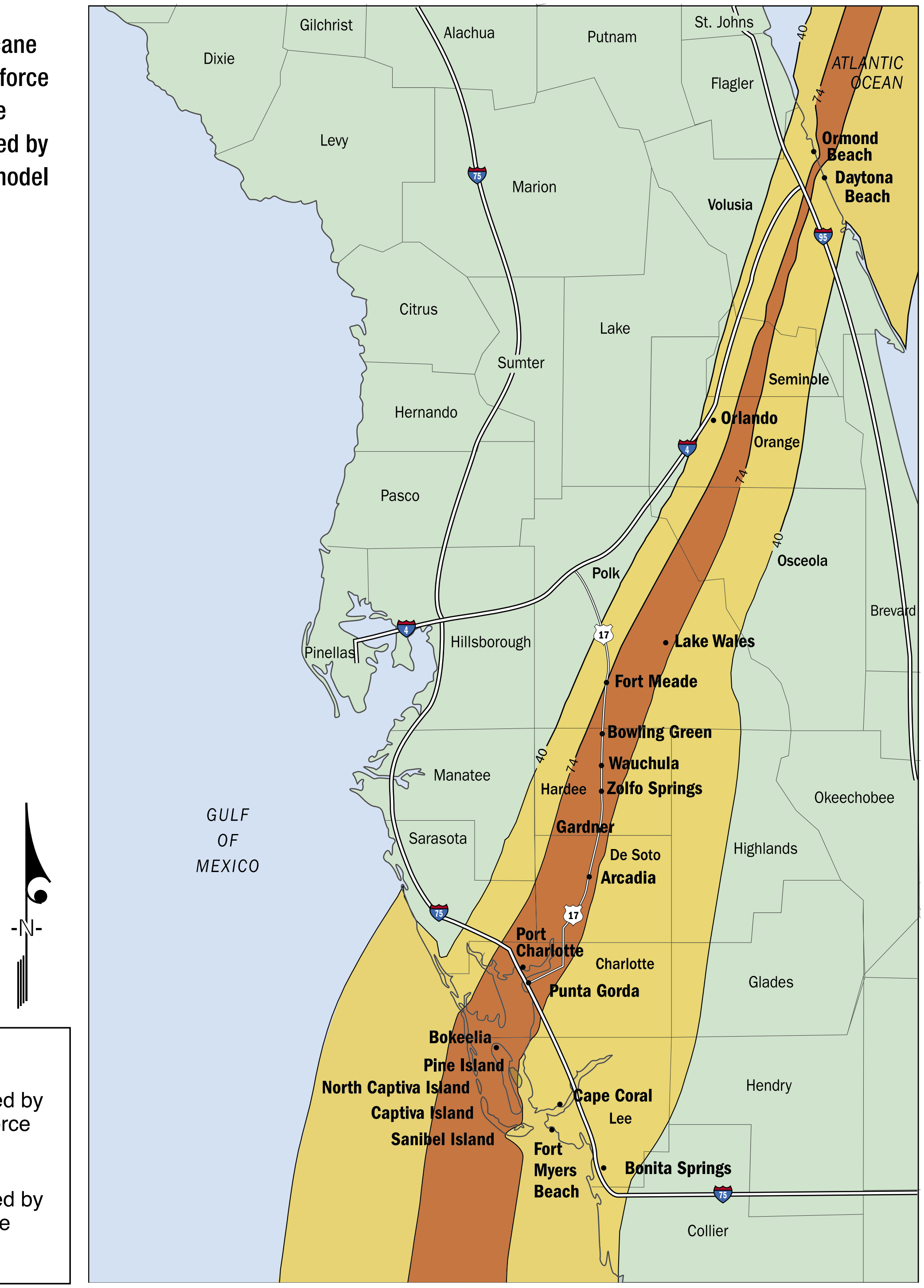
1.1.2 Summary of Storm Surge

As a result of the compact size of Charley and the unexpected eastward turn the hurricane made prior to landfall, the storm surge was not as high as originally predicted by the NHC. The hurricane came ashore as a very narrow, but major hurricane. The radius of the hurricane's eye was estimated to be 6 miles (12 miles in diameter). Hurricane force wind gusts extended outward up to 25 miles from the center; tropical storm force wind gusts extended outward up to 85 miles.

The coastal high water marks were surveyed throughout the impact area. Coastal high water marks along the south-facing Sanibel Island shore were 6 to 8 feet above sea level (asl) (North America Vertical Datum [NAVD] 88). This elevation increased to about 7 to 9 feet asl on the west-facing shore of North Captiva Island. A breach, referred to as "Charley's Gut," was cut across North Captiva Island and was estimated to be 1,500 feet in width. Storm surge elevations along Fort Myers Beach were 5 to 7 feet.

Charlotte Harbor is an estuary that is north of Pine Island and south of Port Charlotte. The Myakka River mouth enters from the west and the Peace River mouth enters from the east, approximately 1 to 1½ miles wide, respectively. Punta Gorda lies on the east shore where the Peace River enters the Charlotte Harbor estuary. High water mark observations along the Port Charlotte shoreline and up the lower Peace River showed that there was no significant storm surge. Water levels appeared to have remained within the normal range of the tide and possibly even below this level. Along Charlotte Harbor south of Punta Gorda to the Charlotte-Lee County line, water levels appeared to have been as high as 3 to 4 feet asl. Additional high water marks after the landfall of Hurricane Charley are presented in Table 1-2.

Figure 1-2. Extent of the hurricane and tropical storm force winds for Hurricane Charley as estimated by the NOAA H-wind model



Legend

Area affected by hurricane force winds

Area affected by tropical force winds

Table 1-2. Additional Storm Surge Depths Observed After Landfall

Location	Storm Surge (asl)
Gasparilla Island, just north of Cayo Costa Island	Estimated between 2 and 3 feet
Along Pine Island Sound, along the sound-facing sides of Captiva and Sanibel Islands	Estimated between 2 and 3 feet
Along the northwest shoreline of Pine Island	Estimated between 4 and 5 feet
Southern shoreline of Pine Island	No significant surge
Along the Caloosahatchee River, 3 to 9 miles upstream of the mouth	Estimated between 1 and 4 feet

1.1.3 Summary of Storm Damage

The effects of the storm were felt across the State of Florida (Figure 1-3) and up into the northeast, as Charley moved up the East Coast. In Florida, the storm caused at least 27 deaths and resulted in the evacuation of over 1 million residents and tourists. Over 2 million people were without power, some of whom remained without power for several weeks. According to the Insurance Services Office (ISO), 640,000 insurance claims were filed, with 605,000 of those in Florida; insured losses from the storm are estimated at $6.8 billion (ISO, 2004). A total of 25 Florida counties were declared under a "state of emergency" and, therefore, eligible for public assistance programs.

Charley took approximately 9 hours to traverse Florida. It was the strongest hurricane to make landfall in the state since Hurricane Andrew in 1992. Just under 36 hours prior to Charley's landfall, Tropical Storm Bonnie struck the Florida Panhandle near Apalachicola. Not since 1906 have two hurricanes struck the State of Florida so close together and not since 1886 (in Texas) have four hurricanes made landfall in the same state in one year. (Hurricanes Charley, Frances, Ivan, and Jeanne all hit the State of Florida in 2004.) Additional information on the history of hurricanes in southwest Florida is provided in Appendix E.

CHARLEY: An overview

Total dead in Florida: At least 27

1.4 million people evacuated

Power knocked out to 2 million.

About 1,500 Florida National Guard members were activated and another 5,000 were called up. Federal "State of Emergency" was declared in 25 counties.

Elsewhere:

Cuba: At least four people were killed, and four others injured. At least 41 buildings in Havana collapsed. More than 200,000 people were evacuated in western and central Cuba.

Jamaica: One person was killed. Flooding left some roads impassable and submerged crops in the southern agricultural region.

North Carolina: Relatively little damage was reported, mostly in the northeastern corner of the state, as Charley weakened to a tropical storm. About 104,000 customers lost power, and there were scattered reports of flooded roads, damaged homes, and downed power lines.

South Carolina: Grand Strand resort area was evacuated and nearly emptied of 180,000 tourists and residents. About 65,000 customers lost power, including 32,000 in the Charleston area.

Other customers without electricity by county

Collier	80,000
Highlands	45,000
Brevard	25,000
Sarasota	16,000
Lake	11,498
Flagler	10,000
Hendry	2,000
St. Johns	2,000
Glades	1,000
Hillsborough	300

SOURCES: ESRI, GDT, ASSOCIATED PRESS, NATIONAL HURRICANE CENTER, U.S. CENSUS BUREAU, FLORIDA POWER & LIGHT, TAMPA ELECTRIC, PROGRESS ENERGY, AND THE ORLANDO UTILITIES COMMISSION

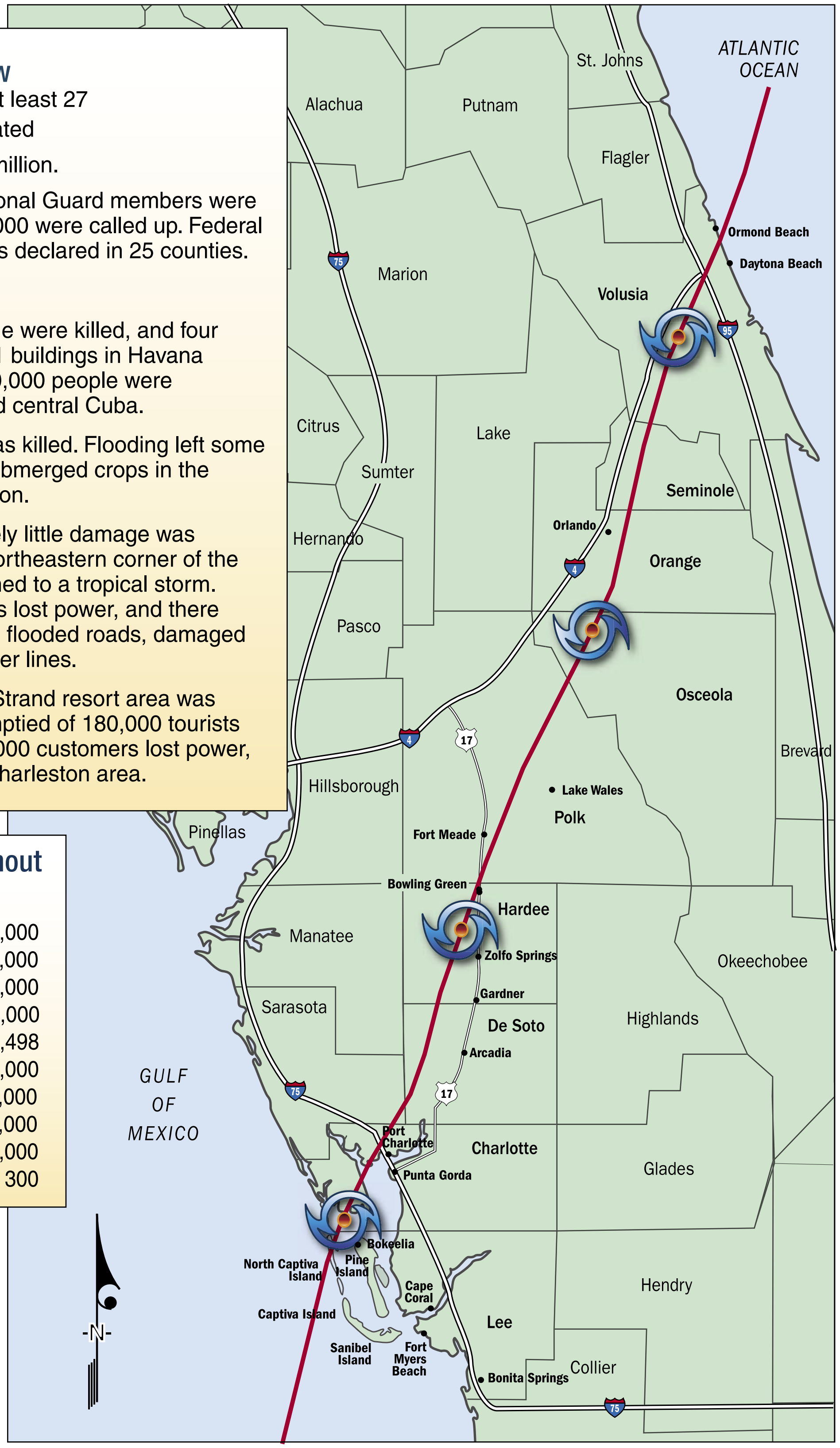


Figure 1-3. Map of Hurricane Charley's path of destruction

Lee County

Population: 440,888

Population 65 and older:..............................112,111

Manufactured (mobile) homes: 23,885

Customers without electricity: 145,000

Fort Myers population: 48,208

Captiva population: 379

Sanibel population: 6,064

1 death

County property appraiser estimated 250,000 building structures, homes, and churches were damaged. Extensive damage was reported on Captiva Island. Mayor of Sanibel Island said bridge to the island would be closed until Lee County officials could assess its engineering and structural integrity. About 20,000 residents of Fort Myers Beach, Captiva Island, and Sanibel Island were prevented from returning home.

Charlotte County

Population: 141,627

Population 65 and older: 49,167

Manufactured (mobile) homes: 6,440

Customers without electricity: 80,000

Charlotte Harbor population: 3,647

Punta Gorda population: 14,344

4 deaths

Sheriff's office and Emergency Operations Center were not operational. Two shelters were slightly damaged. Seven fire stations were heavily damaged. Thirty-one mobile home parks suffered major damage. Three hospitals sustained significant damage. Most schools were damaged, some severely. Punta Gorda and Port Charlotte were without water service.

De Soto County

Population: 32,209

Population 65 and older: 6,113

Manufactured (mobile) homes: 1,200

Customers without electricity: 15,000

Arcadia population: 6,604

1 death

Arcadia was without water service. Partial building collapse at Turner Agri-Civic Center, a hurricane shelter where 1,400 people had gathered.

Hardee County

Population: 26,938

Population 65 and older: 3,750

Manufactured (mobile) homes: 354

Customers without electricity: 2,173

Wauchula population: 4,368

Zolfo Springs population: 1,641

Polk County

Population: 483,924

Population 65 and older: 88,738

Manufactured (mobile) homes: 32,640

Customers without electricity: 96,324

Fort Meade population: 5,691

2 deaths

Osceola County

Population: 172,493

Population 65 and older: 19,709

Manufactured (mobile) homes: 4,854

Customers without electricity: 19,945

Four wells at water treatment plant shut down. Multiple fire stations were damaged. Mandatory curfew from 8 p.m. to 6 a.m.

Orange County

Population: 896,344

Population 65 and older: 89,959

Manufactured (mobile) homes: 14,027

Customers without electricity: 330,391

Orlando population: 185,951

1 death

Roofs were torn off three terminals and two giant glass panels blew in at Orlando International Airport, where more than 1,000 people spent the night, Major theme parks reopened the next day.

Seminole County

Population: 365,196

Population 65 and older: 38,853

Manufactured (mobile) homes: 2,908

Customers without electricity: 20,000

Volusia County

Population: 443,343

Population 65 and older: 97,811

Manufactured (mobile) homes: 20,495

Customers without electricity: 196,136

Daytona Beach population: 64,112

1 death

NOTE: The number of manufactured (mobile) homes in any county comes from the Federation of Mobile Home Owners of Florida and may actually be 10 percent higher to account for the number of owners who do not have to register.

Figure 1-3. Map of Hurricane Charley's path of destruction (continued)

1.2 Comparisons of Predictions and Post-Landfall Estimates: Wind

In order to place damage and windborne debris observations in context, reliable estimates of wind speeds are needed. Unfortunately, no surface level wind speed measurements were obtained that directly support the estimated maximum wind speeds of the hurricane at landfall.[1] For wind speeds to be useful in evaluating damages, it is important to report the wind speed along with the averaging time (sustained vs. gust), the height above ground, and the roughness of the area around the wind speed (expressed as Exposure Category A, B, C, or D, as defined in the Florida Building Code (FBC) and in the American Society of Civil Engineers' (ASCE's) *Minimum Design Loads for Buildings and Other Structures* (ASCE 7). Unless otherwise noted, wind speeds will be reported as 3-second peak gust, Exposure C, over land. (See sidebar.)

Exposure Category

A = Large city centers

B = Urban and suburban terrain

C = Open terrain and open water under hurricane conditions

D = Open water (non-hurricane conditions)

For more information, see Section 1606.18 of the FBC or Section C6 of ASCE 7.

Note: Exposure A was deleted in Section 6 and the associated commentary of the 2002 edition of ASCE 7.

1.2.1 Predictions

Hurricane Charley was upgraded from a Category 2 to a Category 4 storm based on a rapid intensification in winds measured by dropsonde from a U.S. Air Force Reserve/NOAA hurricane hunter aircraft less than 6 hours prior to landfall. The NHC report on Hurricane Charley (NHC, October 2004) lists the minimum control pressure at landfall at 941 millibars and the central pressure near Punta Gorda at 942 millibars in its best track estimates. The final advisories prior to landfall stated that the northeast quadrant of the storm, as is typically the case, contained higher winds and that the areas east of the track of the center of the hurricane could experience these high winds.

1.2.2 Post-Landfall Observations

Hurricane Charley was a very intense, but very narrow hurricane. By the time the hurricane had moved 20 miles inland from the barrier

[1] Doppler radar measurements for these areas may become available, but no indication has been made from the weather services in Florida to indicate that a high-wind measurement was captured with Doppler radar. However, even if such a measurement had been obtained, these readings only measure the component of wind velocity directed toward or away from the radar site. Furthermore, the surface along which the Doppler radar measurements are taken angles upward away from the radar unit so the values typically correspond to elevations well above the height of buildings and structures considered in this study.

islands, the swath of damage to trees and structures was only about 15 miles wide. The MAT is aware of approximately 9 reported tornadoes from this event (NHC, October 2004). The members of the MAT did not observe damage consistent with tornadoes during the course of the assessment. Wind damage was most severe to the east of the path of the center (eye) of the hurricane shown in Figure 1-3.

Because the highest expected wind speeds at landfall were not measured, model-based assessments of wind speeds are the only practical option for estimating actual surface level wind speeds in the areas where MAT investigations were conducted after Hurricane Charley. To date, the best known and most scientifically based estimates of wind speeds available in the public domain are those produced by the NOAA Atlantic Oceanographic and Meteorological Laboratory's Hurricane Research Division (HRD) using a program called H-wind (*Weather and Forecasting*, September 1996.) Past experience with H-wind-based analyses suggests that the model provides reasonably accurate estimates of the maximum wind speeds. The largest differences between measured and predicted values typically occur for lateral distributions of winds and the decay of winds as the storm progresses inland. Contours of sustained, 1-minute wind speeds from the H-wind analysis are shown in Figure 1-4. A second modeling approach that usually produces reasonable estimates of maximum wind speeds and lateral distributions of winds involves the use of wind field based models such as the one in FEMA's Hazards U.S. – Natural Hazard Loss Estimation Methodology (HAZUS-MH) and described in the *Journal of Structural Engineering* (ASCE, October 2000, pp. 1203-1221). The wind field analysis conducted by Applied Research Associates (ARA) using this model, with some adjustments, is shown in Figure 1-5. Despite their totally independent approaches to wind speed estimates, the maximum wind speeds for Hurricane Charley agree within approximately 3 mph between the H-wind and ARA analyses. There are, however, large differences between the locations of the highest winds. The following discussion provides estimates of wind speeds in the various areas visited by the MAT.

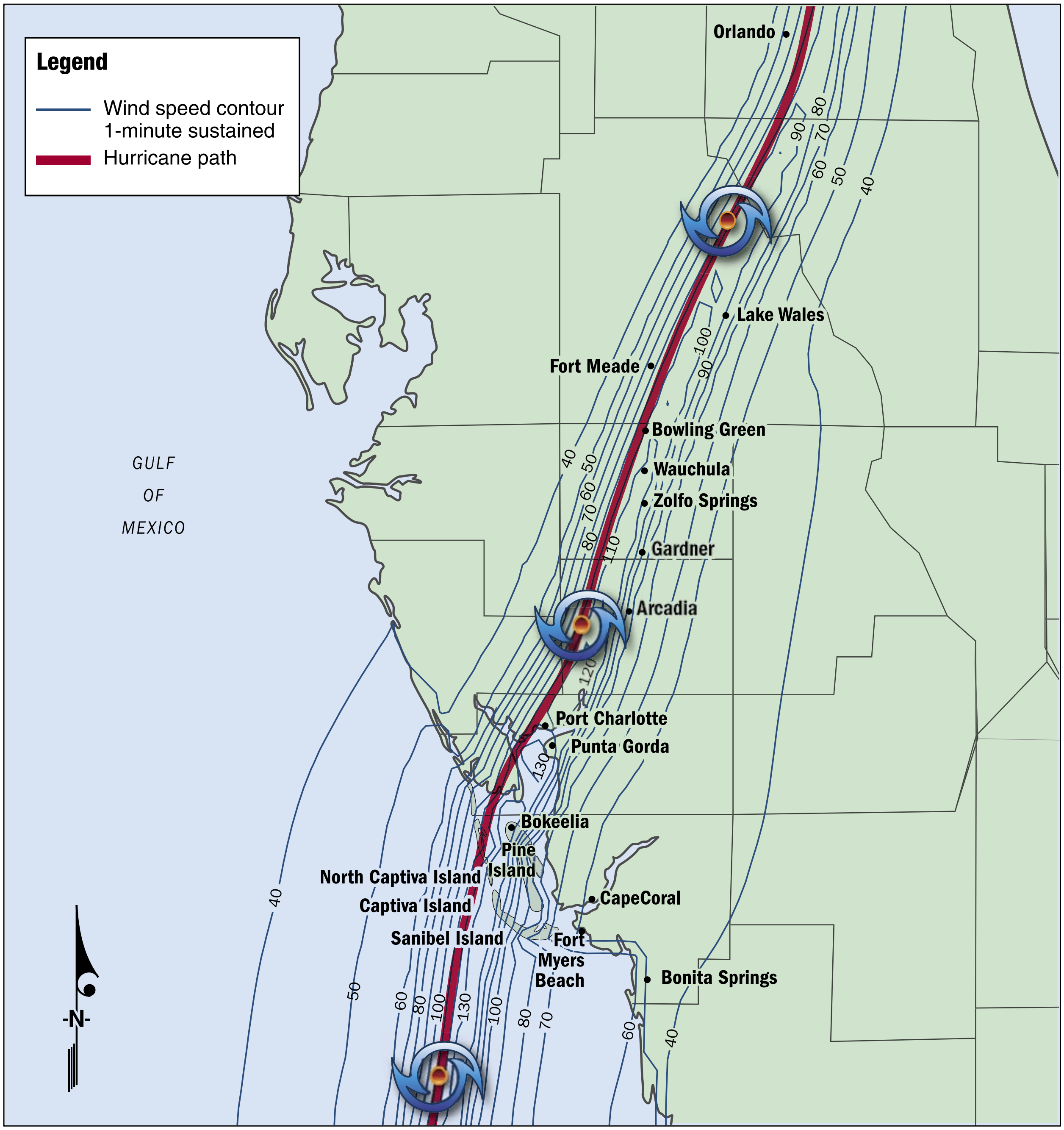


Figure 1-4 **Results of the preliminary H-wind swath analysis for Hurricane Charley** (NOAA/HRD)

1.2.3 Reported Data

In addition to the wind measurements presented in Section 1.1.1, only very limited reported surface wind data are currently available for Hurricane Charley. The two highest unofficial observations reported by the NHC (NHC, October 2004) are detailed below:

- Table 5 of the NHC report on Hurricane Charley lists a 172-mph gust speed reported from the Charlotte County Medical Center. The anemometer was located on the northwest elevator shaft that extends above the roof of the hospital and was blown off the building during the storm. No written record was available and no wind direction was reported. The medical center staff indicated that the 172-mph wind speed was maintained for some time and should be considered a sustained wind. The NHC, as noted above, reported it as a gust speed. It is possible that the high readings were associated with the failure of the anemometer support and may have reflected accelerated flow around the top of the building. The reported value may be plausible as a gust speed, given the estimated height of the instrument (40 to 50 feet above grade), but is very questionable as a sustained speed.
- Table 5 of the NHC report on Hurricane Charley lists a 160-mph gust speed at the Charlotte County Airport. This site is farther inland than the Charlotte County Medical Center, but at a similar location relative to the track of the storm and is a more open and exposed site. This gust speed is in reasonable agreement with but on the high side of the H-wind and ARA wind field analyses shown in Figures 1-4 and 1-5, respectively, for this distance inland.

1.2.4 Wind Field Estimates – Model-Based Results

Plots of wind speeds estimated using the H-wind and wind field based models are shown in Figures 1-4 and 1-5, respectively. The models suggest 3-second peak gust speeds of 150 to 160 mph or greater occurred at the coast of the barrier island where Charley made landfall. These numbers are a little lower than those suggested by the preliminary H-wind analysis where gust speeds ran 30 percent higher than the sustained wind speeds shown in Figure 1-4 and would be on the order of 160 to 170 mph 3-second peak gust. Center-line path plots of the track of the hurricane shown in Figures 1-4 and 1-5 are based on the data used at the time the models were run. These paths have not been altered to agree because they were prepared by others. The path represented in Figure 1-5 is based on the data provided in the October NHC report and is believed to be the most accurate.

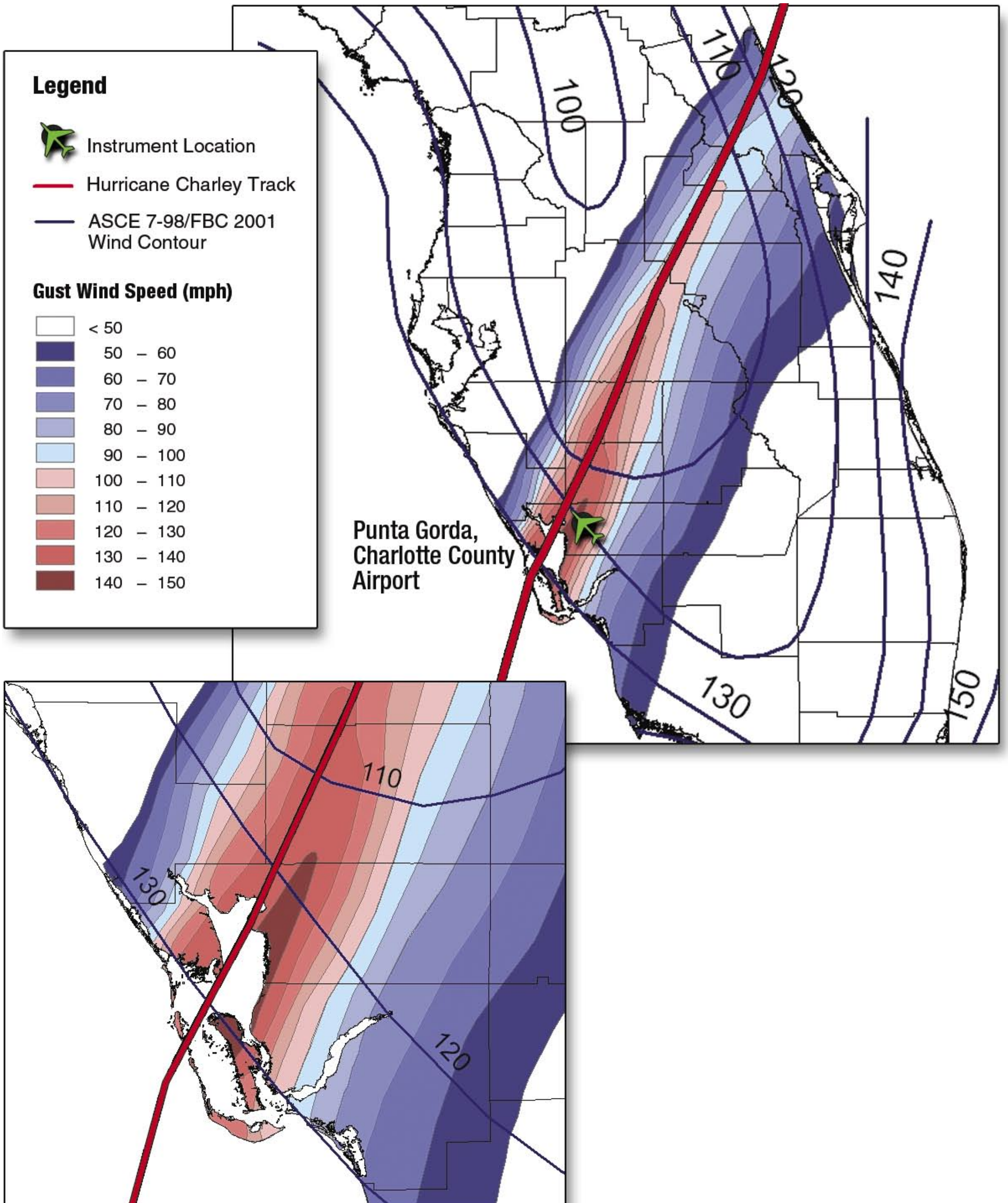


Figure 1-5. Results of the preliminary wind field analysis for Hurricane Charley based on HAZUS-MH wind methodology. The insets provide a close-up of the areas that experienced the highest winds with the design wind speed contour lines from the 2001 FBC overlaid across the wind field. (ARA)

Recognizing the limited information and modeling available at the time this report was prepared, it is possible to only roughly estimate the wind speeds in the various regions surveyed during the MAT. It may never be possible to provide precise estimates of sustained or gust speeds for particular locations. Based on available information, the following estimates are presented by the MAT:

- On Sanibel Island, 3-second peak gust wind speeds likely ranged from 90 mph at the south end of the island to 130 mph toward the northern tip of the island.
- The north end of Captiva Island was subjected to the edge of the eastern side of the eyewall and 3-second peak gust wind speeds were estimated to be between 145 and 155 mph. The built-up northern portion of North Captiva Island experienced the eye of the storm, with strong winds from two radically different directions: easterly winds when it was subjected to the northern eyewall and westerly winds when it was subjected to the southern eyewall. The highest gust wind speeds likely occurred in the region at or below where the cut occurred in North Captiva Island.
- Downtown Punta Gorda (Exposure B terrain – built-up or suburban areas) likely experienced 3-second peak gust wind speeds between 125 and 140 mph and the equivalent Exposure C terrain 3-second peak gust wind speeds would likely have been between 140 and 160 mph.
- Areas of Port Charlotte near Charlotte Harbor and extending northeastward through Deep Creek likely also experienced 3-second peak gust wind speeds between 125 and 140 mph in Exposure B terrain. Properties along the waterfront and in Exposure C terrain located between Charlotte Harbor and Deep Creek likely experienced 3-second peak gust wind speeds as high as 140 to 160 mph.
- In the areas around Arcadia, the 3-second peak gust wind speeds in the hardest hit Exposure B terrain were probably on the order of 110 to 120 mph and Exposure C terrain in the hardest hit areas likely experienced gust wind speeds of 125 to 140 mph.
- Three-second peak gust wind speeds in the hardest hit areas of the cities of Wauchula and Zolfo Springs probably ranged between 100 mph and 115 mph for Exposure B terrain and between 115 mph and 130 mph for Exposure C terrain.
- Three-second peak gust wind speeds in the hardest hit areas around Lake Wales probably ranged between 95 mph and 110 mph for Exposure B terrain and between 110 mph and 125 mph for Exposure C terrain.

- Three-second peak gust wind speeds in the hardest hit areas around Orlando probably ranged between 90 mph and 105 mph for Exposure B terrain and between 105 mph and 120 mph for Exposure C terrain.

Figure 1-4 shows results of the H-wind swath analysis for Hurricane Charley expanded out to show the storm track from Charlotte Harbor to Orlando. This analysis is based on data that were available in real time as the storm approached, struck, and crossed Florida (these data were compiled from NOAA and other agencies using aircraft, buoy, global positioning system (GPS) dropsondes, C-MAN, and surface level anemometer measurements). Generally, when sufficient additional data are retrieved after the storm's passage, a final reanalysis is conducted. Figure 1-4 represents a preliminary analysis of Hurricane Charley, but a final analysis has not yet been conducted. Figure 1-5 shows similar results for maximum gust speeds over open terrain from the ARA wind field analysis. Note that the H-wind values (1-minute sustained) need to be increased by approximately 30 percent before comparing them with the gust values in Figure 1-5.

1.3 Comparisons of Predictions and Post-Landfall Observations: Storm Surge

After every storm event, Federal, state, and research agencies study the forecasts and predictions of the storm event in order to compare them to the actual event. Even as Hurricane Charley was making landfall on the southwest coast of Florida, the NHC and NOAA were updating their predictions with real-time data from the field.

One of the prediction models used by the NHC is the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model. Storm surge (the abnormal rise of ocean water on land due mainly to strong onshore winds and a decrease in barometric pressure) is primarily forecast with the SLOSH computer model. SLOSH is run by the NHC to estimate storm surge heights resulting from historical, hypothetical, or predicted hurricanes by taking into account five factors: the wind speeds, the central pressure, the size, the forward speed, and the track direction of the hurricane.

The calculations are applied to a specific locale's shoreline, incorporating the unique bay and river configurations, water depths, bridges, roads, and other physical features. If the model is being used to estimate storm surge from a predicted hurricane (as opposed to a hypothetical one), forecast data must be put in the model every 6 hours over a 72-hour period and updated as new forecasts become available.

1.3.1 Predictions

One of the parameters used in SLOSH is the radius of maximum winds (R_{max}); although some report this the same as the radius of the hurricane's eyewall, this is not always the case. Although Charley was over open water, the R_{max} that was being entered into the model had been as high as 40 miles and as low as 12 miles. Because the last advisory was prepared prior to landfall, the NHC had kept the R_{max} value in the model at 12 miles. However, an aircraft penetration of the hurricane's eyewall just after that time found the winds had increased to Category 4 strength and the radius had decreased to approximately 5 nautical miles. As a result, SLOSH runs performed for the final advisories prior to landfall were calculated on R_{max} values from 40 to 12 miles as the eyewall shrank in size, but a final run of the SLOSH model with the actual 5- to 6-mile R_{max} was not done until after landfall.

Figure 1-6 graphically presents the predicted surges for the R_{max} value of 40 miles; surge heights for the barrier islands and the harbors and bays were predicted to be as high as 12 to 18 feet. The maximum storm surges estimated for this storm by the NHC in the hurricane advisories were for the 40-mile R_{max} illustrated in Figure 1-6. These maximum surges were predicted to occur southward along the coast to approximately Bonita Beach for this larger hurricane. These predicted surge elevations are only for this track and this basin; other areas would have different predicted maximum surges.

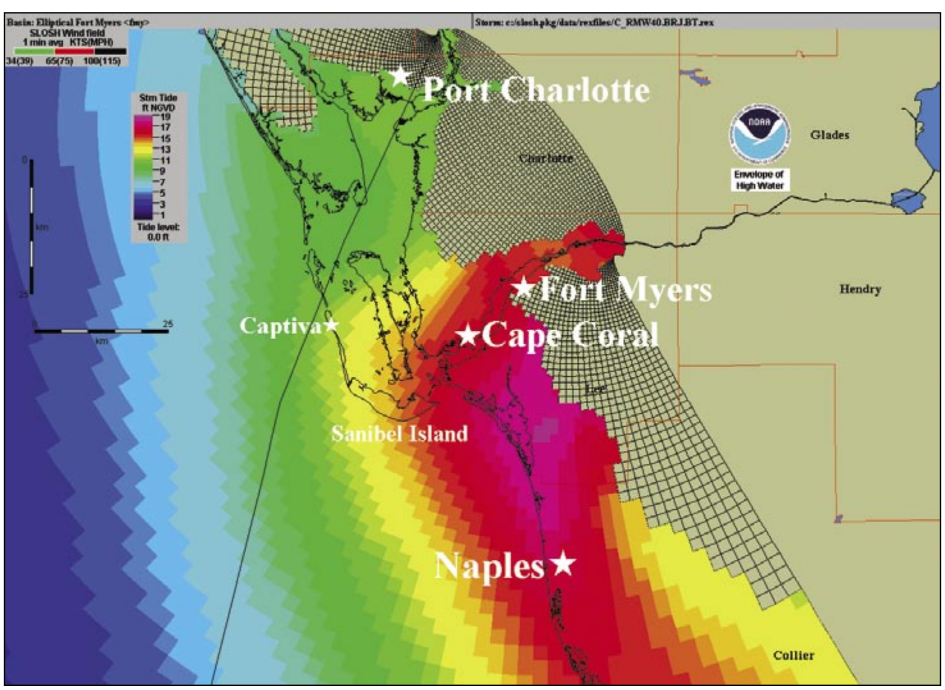


Figure 1-6.
Storm surges computed using the NWS SLOSH model for Hurricane Charley, using R_{max}= 40 miles

(NOAA/NHC)

1.3.2 Post-Landfall Observations

The results of the NHC SLOSH model run with Charley's size and intensity based on the NOAA flight information of an R_{max} = 6 miles (prepared shortly after landfall) are presented in Figure 1-7. As shown, the modeled storm surges reach only 6.7 feet, with values of 5 to 6 feet along the beachfronts of Captiva and Sanibel Islands, and the area from Fort Myers Beach to Bonita Beach.

Storm surge results as predicted by the SLOSH model using the latest data (refer to Figure 1-7) are within the same range as actual high water marks surveyed by FEMA field teams after the storm. This indicates that, although the parameters used in the models are constantly changing, the models are providing realistic values. A more detailed assessment of the Hurricane Charley storm surge will be produced by the NHC as more data are collected. Hurricanes are unpredictable and require constant monitoring to gather real-time data for better model input adjustments and improve surge forecasting.

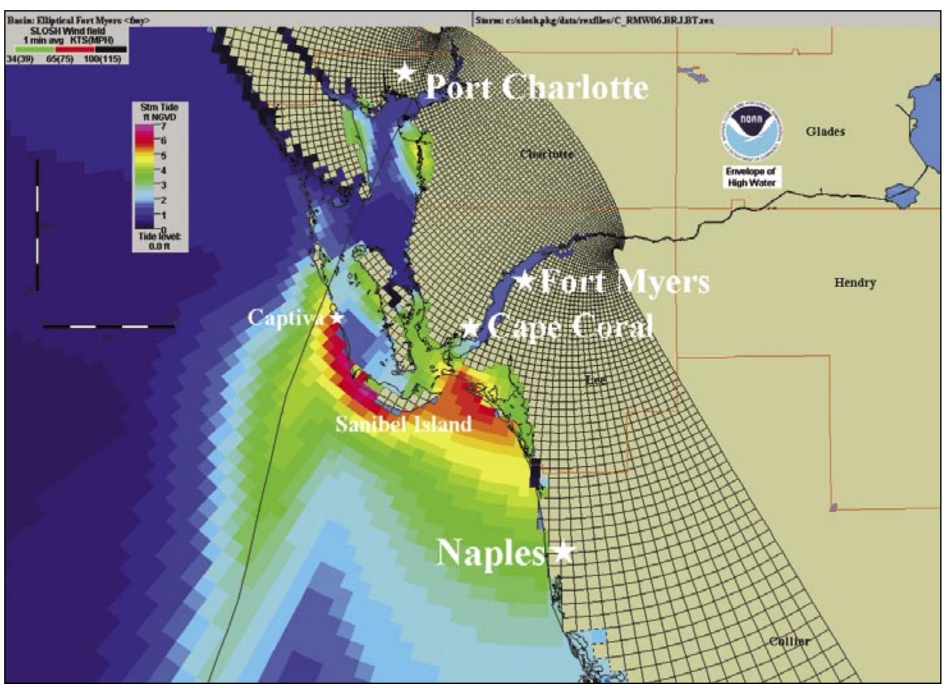


Figure 1-7.
Storm surges computed using the NWS SLOSH model for Hurricane Charley, using R_{max}= 6 miles. The track and intensity remain the same as those in Figure 1-6.
(NOAA/NHC)

1.4 Economic and Social Impacts of Hurricane Charley

Hurricanes can cause economic and social impacts, as well as psychological impacts, that have both short- and long-term effects. These impacts begin at a very personal level with damage to homes and places of employment that affect the lives and livelihoods of individuals and families. Other impacts begin at the community level with loss of function of lifelines and essential facilities such as utilities, police, fire and emergency services, hospitals, schools, and government functions. These impacts can forever alter the fabric of the affected neighborhoods and communities.

1.4.1 Loss Estimates

According to a field report from a National Science Foundation team, the final death toll in Florida was determined to be 27, with $15.4 billion in reported damages and an estimated $6.8 billion in insured losses (ISO, 2004). Table 1-3 presents the ISO and HAZUS-MH loss estimates based on the final storm tracks used by the modelers. It can be seen that the ISO and HAZUS-MH estimates for Hurricanes Charley and Jeanne are very similar, but there are significant differences in the estimates for Hurricanes Frances and Ivan. Initial estimates of industry-wide insured losses have been released by ISO for each of the four hurricanes. Care must be given when directly comparing the ISO estimates with the estimates produced by HAZUS-MH because the ISO estimates include losses for automobiles and boats, appurtenant structure losses, and additional living expenses, yet do not include deductibles or uninsured properties. In spite of these differences, insured loss estimates do provide a useful benchmark for the HAZUS-MH wind loss estimates.

Table 1-3. Summary of Initial ISO Insured Loss Estimates*

Hurricane	Landfall Date	ISO Press Release Date	Initial ISO Insured Loss Estimate ($B)	HAZUS-MH Estimate Based on Final Hurricane Tracks ($B)	States Included
Charley	8/13/04	8/25/04	6.8	7.1	Florida
Frances	9/5/04	9/23/04	4.1	1.8	Florida
Ivan	9/16/04	10/14/04	5.3	1.6	Florida, Alabama, Georgia
Jeanne	9/26/04	10/26/04	2.8	2.8	Florida
2004 Total	**--**	**--**	**18.9**	**13.3**	**--**

*This table was adopted from the internal FEMA report for HAZUS-MH Support for Hurricanes Charley, Frances, Ivan, and Jeanne. Additional information regarding the differences in the lost estimates for Frances and Ivan is presented in that report.

1.4.2 Economic Impacts

From an economic standpoint, jobs and housing are considered two stalwarts of a vibrant economy. Without either, a community cannot thrive. The economic vitality of a community is directly tied to its local businesses that supply goods or services, provide employment, and pay taxes.

Serious aftereffects of a major storm can include temporary or permanent loss of jobs. In addition to businesses being impacted directly after Hurricane Charley because of no power or being heavily damaged or destroyed, the Florida media reported severe impacts to Florida's multi-billion dollar tourism industry.

Florida's $9.1 billion dollar citrus industry was also severely impacted by Charley. The damage caused is the highest since Hurricane Donna in 1960. Approximately 35 percent of the state's citrus groves are located in the prime citrus-growing counties of De Soto, Polk, and Hardee, which saw their trees torn up and their barns and equipment destroyed. This damage has both short-term and long-term effects. The immediate loss is the crop on the trees that was to be harvested beginning in October. The long-term loss is the structural damage to the industry, primarily downed trees that could take years to replace and grow. In addition, consumers across the United States will be impacted by the higher costs of citrus products.

1.4.3 Social and Psychological Impacts

In addition to significant social and psychological impacts resulting from damage to one's home or business, loss of personal belongings, and possible personal trauma, other types of psychological impacts are often felt by communities after a significant hurricane event. These include the impacts of school closures and the price gouging by the service industry that can occur.

School closures. Social and psychological factors may result after a major storm because of school closures and other disruptions to daily life. Schools are mainstays of many communities, and even temporary loss of use can impose difficulties on students, parents, faculty, and the administration during the time a school is not usable. This is illustrated by the following excerpt from The Heinz Center (*Human Links to Coastal Disasters*, 2002):

- "From the standpoint of children and families, after an impact is a particularly bad time for schools to be closed. Damaged homes and neighborhoods are dangerous and depressing places. Children are often left with no safe place to play when yards, playgrounds and recreational programs are lost, no one to play with when playmates and friends are forced to dislocate and parents are too busy dealing with survival and rebuilding issues to have much time for them.
- The closing of a local school is highly disruptive to social networks and, if it becomes permanent, can rob a neighborhood of its identity and cohesion. One of the most dramatic effects that can occur to a severely impacted community is when a school is closed for a long time, maybe even permanently, due to regional depopulation after homes are destroyed.
- Getting schools reopened quickly has been found to be an important step toward rebuilding the community as a whole.
- An understudied area is the long-term effect of major disasters on the education and development of children.
- The shock of being uprooted and moved to a new school, even temporarily, can be very difficult for children. The effects can be particularly traumatic if they occur at a critical developmental time, such as the senior year with its preparation for college and graduation festivities."

Price gouging. Home and business owners can be taken advantage of by unscrupulous contractors. The State of Florida is very proactive in trying to protect its citizens. The Department of Agriculture and Consumer Services oversees a program where homeowners can report incidents of price gouging (http://www.doacs.state.fl.us). In the aftermath of a declared natural disaster, state law also elevates instances of price gouging and unlicensed activities to felony status. In addition, the Florida Home Builders Association (FHBA) has set up a Disaster Contractors Network web site (http://www.dcnonline.org/index.cfm) to provide homeowners with information about licensed contractors.

Economic, social, and psychological impacts can result from injuries received during the storm or in the aftermath while home and business owners, as well as contractors, are making repairs. The information contained in this MAT report will help in developing better building standards, which will reduce damages to housing and businesses, allowing people to return to their homes and go back to work sooner after a major event such as Hurricane Charley.

1.5 FEMA Mitigation Assessment Teams (MATS)

Most people know FEMA for its response to disasters and its assistance to the people impacted by storm events. Another important contribution of the agency involves the scientific and engineering studies that it performs before and after disasters to better understand natural and manmade events. These studies of disasters are conducted with the intent of reducing the number of lives lost to these events and to minimize the economic, social, and psychological impacts on the communities where these events occur.

Since Hurricanes Andrew (Florida) and Iniki (Hawaii) in 1992, FEMA has sent MATs to Presidentially Declared Disaster areas to assess damage caused by hurricanes and to provide recommendations to reduce future damage. After a hurricane, part of FEMA's response is to assess and evaluate the type and severity of damages caused by the event and the magnitude of the storm. Based on the preliminary estimates, FEMA will determine the potential need to deploy one or more MATs to observe and assess damage to buildings and structures from the wind, rains, and flooding. These teams are deployed when FEMA believes the findings and recommendations derived from field observations will provide design and construction guidance that will not only improve the disaster resistance of the built environment in the impacted state or region, but also will be of national significance to all hurricane-prone regions.

1.5.1 Methodology

In response to a request for technical support from the FEMA Disaster Field Office (DFO) in Orlando, FEMA's Mitigation Division deployed a MAT to Florida to assess damages caused by Hurricane Charley. Field investigations to assess building conditions in selected areas affected by the hurricane began on August 19 and concluded on August 24, 2004. The team assessed damage across the width of the storm track, shown in Figure 1-3, from its landfall near the communities on Sanibel and Captiva Islands to inland areas around Orlando. The MAT visited the following towns: Port Charlotte, Punta Gorda, Punta Gorda Isles, Sanibel Island, Captiva Island, North Captiva Island, Fort Myers Beach, Bokeelia/Pine Island, Cape Coral, Arcadia, Gardner, Zolfo Springs, Wauchula, Bowling Green, Fort Meade, Lake Wales, and Orlando.

Single- and multi-family buildings, manufactured housing, and commercial and industrial properties were assessed to determine areas of success or failure as a result of Hurricane Charley. In addition, critical and essential facilities, such as Emergency Operations Centers (EOCs), fire and police stations, hospitals, schools, and storm shelters were also observed to document damage as well as loss of function from this storm. Documentation of observations is presented in this report and in the included photographs and illustrations to relate successes and failures with expected performance in the wind field and surge areas produced by Charley. Conclusions and recommendations, based on the findings of the MAT, that will assist Florida and all hurricane-prone states are provided in Chapters 7 and 8, respectively.

1.5.2 Team Composition

The MAT included FEMA Headquarters and Regional Office engineers and experts from the design and construction industry. Team members from FEMA's database of national experts included structural engineers, architects, wind engineers, civil engineers, a coastal scientist, a technical writer, and building code experts. In addition, representatives from the National Association of Home Builders (NAHB), Institute of Building & Home Safety (IBHS), and National Fire Protection Association (NFPA) also participated on the team.

1.5.3 The Significance of Hurricane Charley

The State of Florida has over 1,300 miles of coastline, thousands of lakes, and hundreds of miles of rivers and is highly prone to hurricanes. Since the devastation caused by Hurricane Andrew, Florida has developed and adopted a state-wide building code, the 2001 Florida Building Code (FBC), which revised the design wind speed map to be used across the state for both residential and commercial construction and provided codified guidance for the protection of buildings from windborne debris. The 1999 edition of the Standard Building Code (SBC) was used as the foundation of the 2001 FBC, both of which based their wind-related requirements on the 1998 edition of ASCE 7, *Minimum Design Loads for Buildings and Other Structures*. The SBC is no longer published; instead, there are three national model codes available to adopting jurisdictions – the International Building Code (IBC), the International Residential Code (IRC), and the NFPA 5000, *Building Construction and Safety Code*. Their wind and debris requirements, in turn, are based upon the provisions specified in later editions of ASCE 7. In fact, since the development of the 2001 FBC, ASCE 7 has been revised twice – once in 2002 and again in 2005.

In addition, the U.S. Department of Housing and Urban Development (HUD) developed a set of high-wind standards for manufactured housing units that were adopted in 1994. The 1994 HUD standards for high-wind regions (wind Zones II and III) use a modified version of the wind load provisions of the 1988 ASCE 7 Standard. Wind Zone III homes would be required near the coast in the Punta Gorda area, but wind Zone II homes would be required roughly inland of Interstate 75. Although HUD sets the standards for design of the manufactured housing units, the states control the installation of the homes using either state rules or manufacturers' recommendations. It was clear that the newer manufactured homes in the Port Charlotte and Punta Gorda areas were being installed using the much closer anchor spacing of 5 feet 4 inches on center per the revised standards rather than the 8 feet on center spacing used on older homes.

Because Florida is so vulnerable to hurricanes, but also proactive in supporting better building codes, the MAT was tasked to develop an understanding of the performance of the building stock, both new (built to the 2001 FBC) and old (built to the SBC) in areas impacted by Hurricane Charley. Specifically, the MAT wanted to assess the performance of various types of buildings, including residential, commercial, and critical/essential facilities in order to understand how building code standards affected performance of the buildings for an event that can be classified as a "code event" near where the storm made landfall.