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GULF POWER
A SOUTHERN COMPANY

September 14, 2007

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COMMISSION CLERK

Ms. Ann Cole, Commission Clerk
Florida Public Service Commission
2540 Shumard Oak Boulevard
Tallahassee FL 32399-0850

Dear Ms. Cole:

Re: Review of 2007 Electric Infrastructure Storm Hardening Plan Filed pursuant to Rule 25-6.0342, F.A.C., Submitted by Gulf Power Company.

Enclosed for official filing in Docket No. 070299-EI are an original and fifteen copies of the following:

1. Prepared rebuttal testimony and exhibit of E. J. Battaglia. 08346-07.
2. Prepared rebuttal testimony and exhibit of A. G. McDaniel. 08347-07

Sincerely,

Susan D. Ritenour
bnh

bh

Enclosures

cc w/encl: Beggs & Lane
Jeffrey A. Stone, Esq.

CMP 2
COM 5
CTR 1
ECR
GCL 2
OPC
RCA 1
SCR
SGA
SEC
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DOCUMENT NUMBER-DATE
08347 SEP 14 07
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DOCUMENT NUMBER-DATE
08346 SEP 14 07
FPSC-COMMISSION CLERK

BEFORE THE FLORIDA PUBLIC SERVICE COMMISSION

IN RE: Review of 2007 Electric Infrastructure Storm Hardening Plan filed pursuant to Rule 25-6.0342, Florida Administrative Code, submitted by Gulf Power Company

Docket No.: **070299-EI**

CERTIFICATE OF SERVICE

I HEREBY CERTIFY that a true copy of the foregoing was furnished by regular U. S. mail, all this 14TH day of September, 2007, on the following:

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BEFORE THE

FLORIDA PUBLIC SERVICE COMMISSION

DOCKET NO. 070299-EI

REBUTTAL TESTIMONY AND EXHIBIT

OF

EDWARD J. BATTAGLIA

September 14, 2007

GULF POWER

A SOUTHERN COMPANY

GULF POWER COMPANY

Before the Florida Public Service Commission
Rebuttal Testimony of
Edward J. Battaglia
Docket No. 070299-EI
In Support of Gulf Power Company's Storm Hardening Plan
Date of Filing: September 14, 2007

Q. Please state your name, business address and occupation.

A. My name is Edward J. Battaglia, and my business address is One Energy Place, Pensacola, Florida 32520. I am the Technical Services Manager for Gulf Power Company. My organization is responsible for providing technical support for the distribution engineering and construction personnel at Gulf. This technical support function includes the Company's Reliability, Design and Construction Specifications, Power Quality, Distribution Geographic Information System (DistGIS), Technical Applications, such as the Company's Job Estimating and Tracking System, and large project engineering.

Q. Are you the same Edward J. Battaglia who provided direct testimony on Gulf Power's behalf in this docket?

A. Yes.

Q. Have you prepared an exhibit that contains information to which you will refer in your testimony?

A. Yes. I have one exhibit consisting of nine schedules to which I will refer. These schedules were prepared under my supervision and direction.

Counsel: We ask that Mr. Battaglia's Exhibit EJB-2, consisting of nine schedules, be marked for identification as Exhibit No. ___.

Q. What is the purpose of your rebuttal testimony in this proceeding?

A. I will address the direct testimony of Mr. R. L. Willoughby and Mr. Peter J. Rant filed on behalf of the City of Panama City Beach, Florida and the City of Panama City Beach Community Redevelopment Agency concerning Gulf Power Company's Storm Hardening Plan (the "Plan") for the period 2007 through 2009 as amended on August 14, 2007. Specifically, I will address how their analysis and assumptions are flawed in asserting that undergrounding can be applied in a blanket fashion as a "meaningful tool for storm hardening, a tool that can greatly reduce restoration costs and that can greatly improve reliability in a storm situation."

Q. Do you agree with Mr. Willoughby and Mr. Rant's conclusion that Gulf failed to consider undergrounding as a storm hardening activity?

A. No. As discussed in my direct testimony, Gulf adequately considered transitioning to underground as a storm hardening option in the development of its Plan. Gulf relied on its many years of storm restoration experience, both on Gulf's system and in helping other utilities, as well as its experiences from Hurricanes Ivan and Dennis, to formulate a plan to meet the requirements of Rule 25-6.0341 and 25-6.0342, Florida Administrative Code.

While there is no empirical forensic data showing the exact storm impacts from Hurricanes Ivan and Dennis, field observations by Gulf personnel involved in the restoration effort after these hurricanes were used as an input for determining how to storm harden Gulf's system. Schedule 1 of my exhibit has several pictures showing some of the damage from hurricanes that impacted Gulf's system. Along with this base of knowledge, Gulf also incorporated its experience with day-to-day operation and maintenance of its electric system.

In adopting a storm hardening activity, Gulf considers both cost-effectiveness and whether the activity meets the goal of reduced customer outages and restoration times. In reviewing an activity for implementation, the Company looks at how the activity would further the goal of reduced customer outages and restoration times both in the aftermath of a storm occurrence and also on a day-to-day operations basis. At this time, Gulf's experience with underground distribution does not support wide spread use of undergrounding as a storm hardening activity. Although underground distribution appears to be an attractive method of avoiding wind damage during a storm event, underground construction has limitations that cause additional issues on a day-to-day operational basis and during storm restoration. For example, underground construction results in increased cost for initial installation, normal operation and maintenance and storm restoration situations. Finding and repairing damage to underground facilities after a storm event and on a day-to-day basis takes longer resulting in longer outages. Mr. Rant apparently believes that all underground facilities are loop fed, which is simply not the case. If all new underground were loop fed, the cost of underground would be even greater. Even in the case of loop fed underground, it is still susceptible to storm surges and to damage during clean-up after storms. Undergrounding also presents challenges to the goal of facilitating safe and efficient access to facilities. Gulf's first hand experience is that padmounted equipment gets covered up both in the initial clearing of sand and debris from roads and in the piling of debris on road rights-of-way as customers work through the restoration process of their homes and businesses. This poses a major safety concern for both the public and for utility personnel operating, troubleshooting or repairing the equipment and adds time to the restoration process. In addition, padmounted equipment associated with underground facilities is subject to damage by the debris movers in the process of pushing and loading the debris onto trucks.

Q. Does this mean Gulf is opposed to further consideration of undergrounding as a potential future storm hardening activity?

A. No. Gulf is conducting several distribution projects to test their potential as storm hardening techniques. Gulf is piloting underground storm hardening techniques as discussed in its Plan and contained within Appendix 6 of the Plan. These are being done in potential storm surge areas to test the effectiveness of mitigation techniques. Some of these are: continuing to use non-corrosive cabinets for equipment, below grade switch gear, and anchoring vaults with concrete filled pilings.

Q. Does Gulf have a process in place for collecting additional data on undergrounding as a storm hardening activity?

A. Yes. The process consists of O&M data collection and elements of the Ten-Part Storm Preparedness Plan initiatives (Ten-Part Initiatives). This includes the development of a Geographic Information System (GIS), post storm data collection and forensic analysis, the collection of outage data differentiating between overhead and underground systems, and participation in collaborative storm hardening research with other utilities through the Public Utility Research Center (PURC) at the University of Florida. In addition, the process includes the installation of Gulf's own wind monitors to provide the granular weather data needed to support the forensic data analysis.

Q. In their testimonies, Mr. Willoughby and Mr. Rant describe their experience with how underground fares in storm situations. Do you believe the underground situations they describe are comparable to circumstances existing in Northwest Florida?

A. No. Gulf has approximately 7,200 miles of distribution line with approximately 1,400 miles (20 percent) of the distribution system being underground; in contrast, Mr. Willoughby's experience is based on two small electric systems. Based on the web pages of the respective utilities, the City Of Washington, electric utility operation, has approximately

12,000 customers and 350 miles of line with approximately 10%-15% (35-53 miles) underground. The City of Kinston, electric utility operation, has approximately 12,400 customers and 450 miles of distribution. A table indicating this data is provided in Schedule 2 of my exhibit.

Mr. Rant's testimony indicates no first hand experience with the impact of storms on distribution facilities or storm restoration work. While employed by Brunswick Electric Membership Corporations, he worked on an overhead to underground conversion on barrier islands on the coast of North Carolina. Since the conversion, this system has been impacted by one tropical storm, Ernesto, which occurred in 2006. The National Weather Service shows that Ernesto made landfall at Oak Island, NC. The storm surge produced by Ernesto was about 3 feet at Wrightsville Beach which is approximately 40 miles from Oak Island. Ernesto did produce torrential rainfall and floods in eastern North Carolina. It appears the storm surge was not significant. There are immediate and long-term effect differences when pad mounted equipment is flooded by rainfall versus immersed in a saltwater bath. In addition, Northwest Florida is noted for its "sugar white" beaches. This sand is of a very fine nature which quickly erodes and is carried easily in a storm surge. A single tropical storm provides no real information about the benefits of undergrounding, though it appears this is the sole basis of Mr. Rant's conclusions on undergrounding as a storm hardening activity. As indicated in Schedule 1 of my exhibit, Gulf's experience with underground distribution facilities on barrier islands tells a much different story.

In addition, Mr. Willoughby and Mr. Rant do not discuss the differences in terrain, age of the system, storm intensity experienced, level of storm surge experienced, seawall protected areas versus those with no seawall, or proximity of beach waterline to facilities in coming to their conclusion that undergrounding is an effective storm hardening activity for Gulf.

Q. Mr. Willoughby discusses several named storms as a basis for his conclusions regarding undergrounding as a storm hardening activity. Do these storms provide a sound basis for comparison of storm impacts on Gulf's system?

A. No. Mr. Willoughby stated at page 6 of his testimony that "As City Manager of Washington, North Carolina from 1996 to 2003, I was head of Washington's city government when our electric utility system experienced 5 named storms. Hurricane Fran in 1996, Hurricane Bertha in 1996, Hurricane Bonnie in 1998, Hurricane Dennis in 1999, and Hurricane Floyd in 1999". Schedules 3, 4, 5, 6, and 7 of my exhibit are the National Weather Services storm reports for each of the above named storms. A summary of my research of these storms is as follows:

1. Hurricane Fran - 1996 - landfall near Cape Fear, NC - 159 miles from Washington, NC. Fran was a mid-level category 3 storm at landfall.

2. Hurricane Bertha - 1996 - landfall midway between Wrightsville and Topsail Beaches - 121 miles from Washington, NC. Bertha was a mid-level category 2 storm at landfall.

3. Hurricane Bonnie - 1998 - Landfall near Wilmington, NC - 121 miles from Washington, NC. Bonnie was a high category 2 storm at landfall.

4. Hurricane Dennis - 1999 - Landfall at Cape Lookout National Seashore, NC - 86 miles from Washington, NC. At landfall, Dennis was a strong tropical storm.

5. Hurricane Floyd - 1999 - Near Cape Fear, North Carolina - 159 miles from Washington, NC. Floyd was a mid-level category 2 storm at landfall.

Schedule 8 of my exhibit is a map with the North Carolina hurricane tracks for these storms and it shows the location of the City of Washington. Although the tracks of these storms, may have been in the vicinity of Washington, given this information, it does raise in my mind doubts as to the level of storm impact which would be experienced by the City of Washington upon which Mr. Willoughby is basing his judgment and recommendations on underground. Hurricane impacts can vary significantly, even those of the same category, in the level of wind damage and storm surge damage experienced depending upon how tight the high winds are to the eye of the storm and the tide level at landfall. Also, it is not only the force of the storm surge on objects such as homes and padmounted equipment which creates massive problems, but a storm surge off the Gulf of Mexico consists of a salt water sand slurry which infiltrates and fills everything in its path.

Q. Do you agree with Mr. Rant's analysis regarding the impacts of hurricanes on Gulf's distribution system?

A. No I do not. Mr. Rant's analysis is flawed in many respects. First, Mr. Rant bases his analysis on one storm, Hurricane Dennis in 2005. He states that the conditions experienced in Dennis were fairly comparable in Panama City Beach and in Pensacola. He goes on to say that "In fact, comparable detailed data for the two cities indicates that the storm conditions experienced in Panama City Beach were worse than in Pensacola." This is just not the case. As shown in Mr. Rant's exhibit PJR-2, the data in Table 3 of the National Hurricane Center's final report shows that Pensacola had wind observations as great as 71 knots sustained and gusts as high as 81 knots. This is shown on page 12 of the report. Additional wind data for Hurricane Dennis is shown in Schedule 9 of my exhibit. Gulf captured data from the National Weather Source, which shows a more detailed picture of the wind field from Hurricane Dennis and clearly shows Pensacola experiencing greater winds than Panama City Beach. In addition, to rely on Mr. Rants analysis to make sound engineering judgments in respect to underground and overhead, one must know where the overhead and underground facilities are located within each city, their vegetation conditions, their proximity to the Gulf, their elevations, the "granular" wind data, the details of the damage to the facilities, the causes of damage and other similar data. In other words, in order to do a fair and unbiased assessment of the merits of overhead and underground in respect to storm hardening options, one must do what Gulf has proposed in its Storm Hardening Plan. The analysis needed is far more complicated than the analysis done by Mr. Rant. Gulf's plan is composed of establishing methodologies for collecting the needed metrics, including cost and engineering data. The engineering data involves the collection of daily outage data and storm outage data including the when, where and how, which can be fed into Gulf's GIS to be analyzed by Gulf's engineers. The Plan incorporates the Ten-Part Initiatives which will enable Gulf to do the level of analysis to better evaluate the undergrounding issue. This includes GIS development, a post storm data collection and forensic analysis, the collection of outage data differentiating between overhead and underground systems, and participation in collaborative storm hardening research with other utilities through PURC at the University of Florida. In addition, it involves the installation of Gulf's own wind monitors to provide the granular weather data needed to support the forensic data analysis. Gulf maintains that the analysis which Mr. Willoughby and Mr. Rant speak of in their testimony is already underway through these initiatives. In fact, collaborative research through PURC has already produced a preliminary draft report and the final report is due March 30, 2008. In summary, the measurements used by Mr. Rant to form his opinion do not make a strong or compelling endorsement of undergrounding as a storm hardening option.

Q. In Mr. Rant's testimony, he uses data provided by Gulf to form the opinion that underground facilities fare much better than overhead facilities. Do you agree with his analysis?

A. No I do not. Again Mr. Rant's analysis has many flaws. He forms an opinion that reliability for Gulf's customers in Panama City Beach (PCB) is better than Pensacola's because PCB has a higher percentage of underground distribution. Mr. Rant's conclusion is incorrect. First, comparing Pensacola and PCB is not an "apples to apples" comparison. There are many factors which make this type of comparison difficult, if not impossible, including the age of facilities, vegetation, yearly storm patterns in terms of wind, rain and lightning, geographic differences, vehicle volume and traffic flows, and construction activity.

In response to Mr. Rant's discussion of CAIDI (Customer Average Interruption Duration Index) data, his logic is not supported by the facts. In order to evaluate this issue, it is more appropriate to look at the data for overhead and underground within the same city. Such an analysis shows that for any of the three cities, for any year, CAIDI is always much higher for underground than overhead. Longer duration outages is an inherent characteristic with underground, it is what you would expect, even with using the latest underground technology.

Q. Is it Gulf's position that undergrounding is definitely not a storm hardening option?

A. No, it is possible. Gulf is very concerned with the cost ramifications and associated impact to its customers. If Gulf were to replace the overhead system with underground in just three cities in the Company's service area, Pensacola, Fort Walton Beach and Panama City Beach, the cost is estimated to be $780 million. This cost estimate is approximately 150% higher than the amount of Gulf's total system net distribution investment at the end of 2006. Gulf asserts that it is inappropriate to take an issue as complex as this one and make a decision based on just a few assumptions. Proper analysis requires in-depth study based on factual data to ensure that we do not simply trade off one set of problems for another and that there is indeed value to all of our customers. As previously discussed, Gulf's Plan incorporates the Ten-Part Initiatives which will enable Gulf to do the level of analysis to better evaluate the undergrounding issue.

Q. Does this conclude your rebuttal testimony?
A. Yes.

AFFIDAVIT

STATE OF FLORIDA)
)
COUNTY OF ESCAMBIA)

Docket No. 070299-EI

Before me the undersigned authority, personally appeared Edward J. Battaglia, who being first duly sworn, deposes, and says that he is the Manager of Technical Services of Gulf Power Company, a Florida corporation, that the foregoing is true and correct to the best of his knowledge, information, and belief. He is personally known to me.

Edward J. Battaglia
Manager of Technical Services

Sworn to and subscribed before me this 13th day of September, 2007.

Linda C. Webb
Notary Public, State of Florida at Large

Commission No. DD 541216

My Commission Expires May 31, 2010

LINDA C. WEBB
Notary Public-State of Florida
Comm. Exp. May 31, 2010
Comm. No. DD 541216

Underground and Under sand

Florida Public Service Commission
Docket No. 070299-EI
GULF POWER COMPANY
Witness: E. J. Battaglia
Exhibit No. _____ (EJB-2)
Schedule 1
Page 1 of 10

PAD MOUNTED EQUIPMENT MAY NOT SURVIVE AS WELL AS FLUSH MOUNTED EQUIPMENT IN STORM SURGE

Florida Public Service Commission
Docket No. 070299-EI
GULF POWER COMPANY
Witness: E. J. Battaglia
Exhibit No. ____ (EJB-2)
Schedule 1
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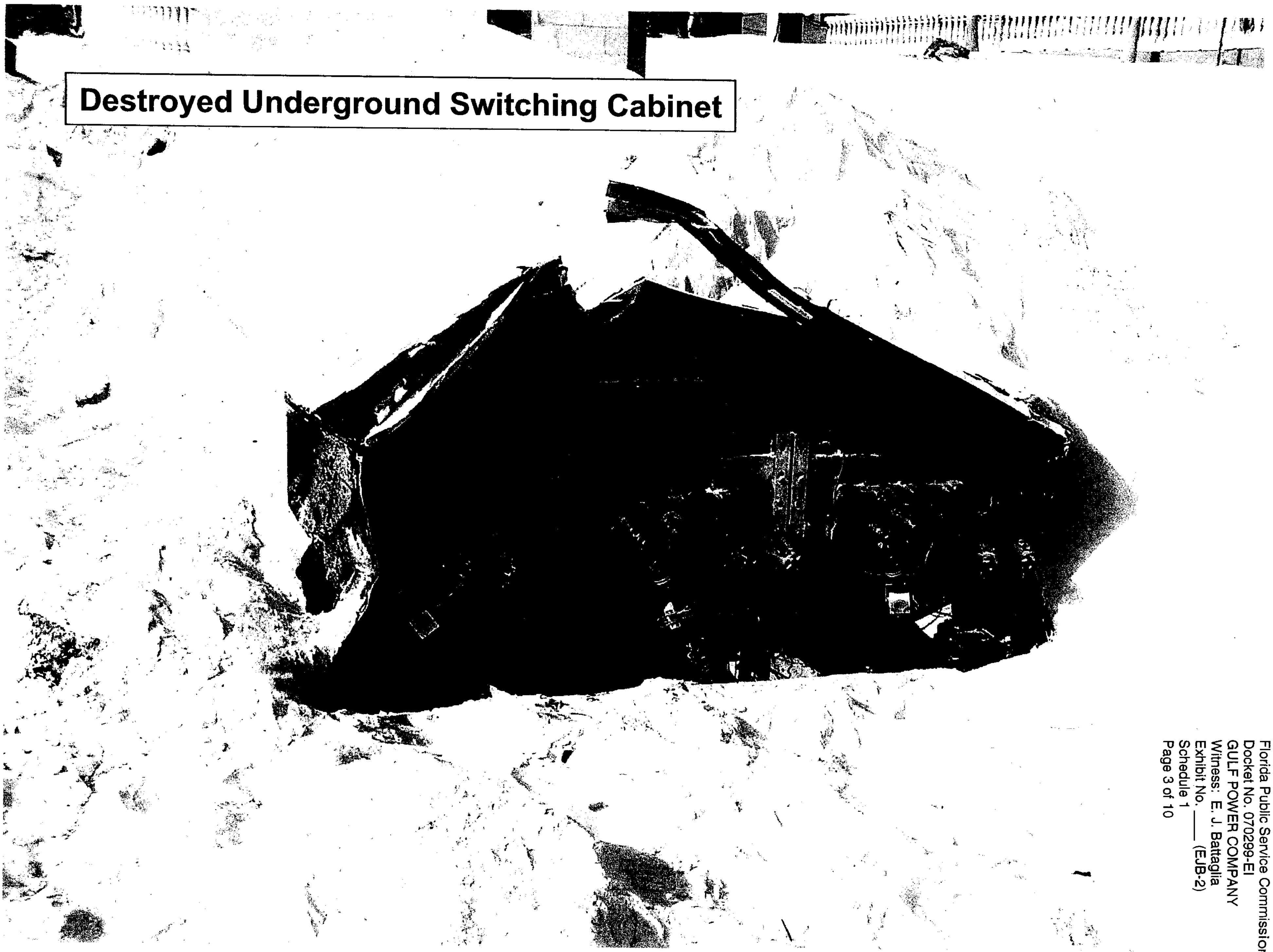
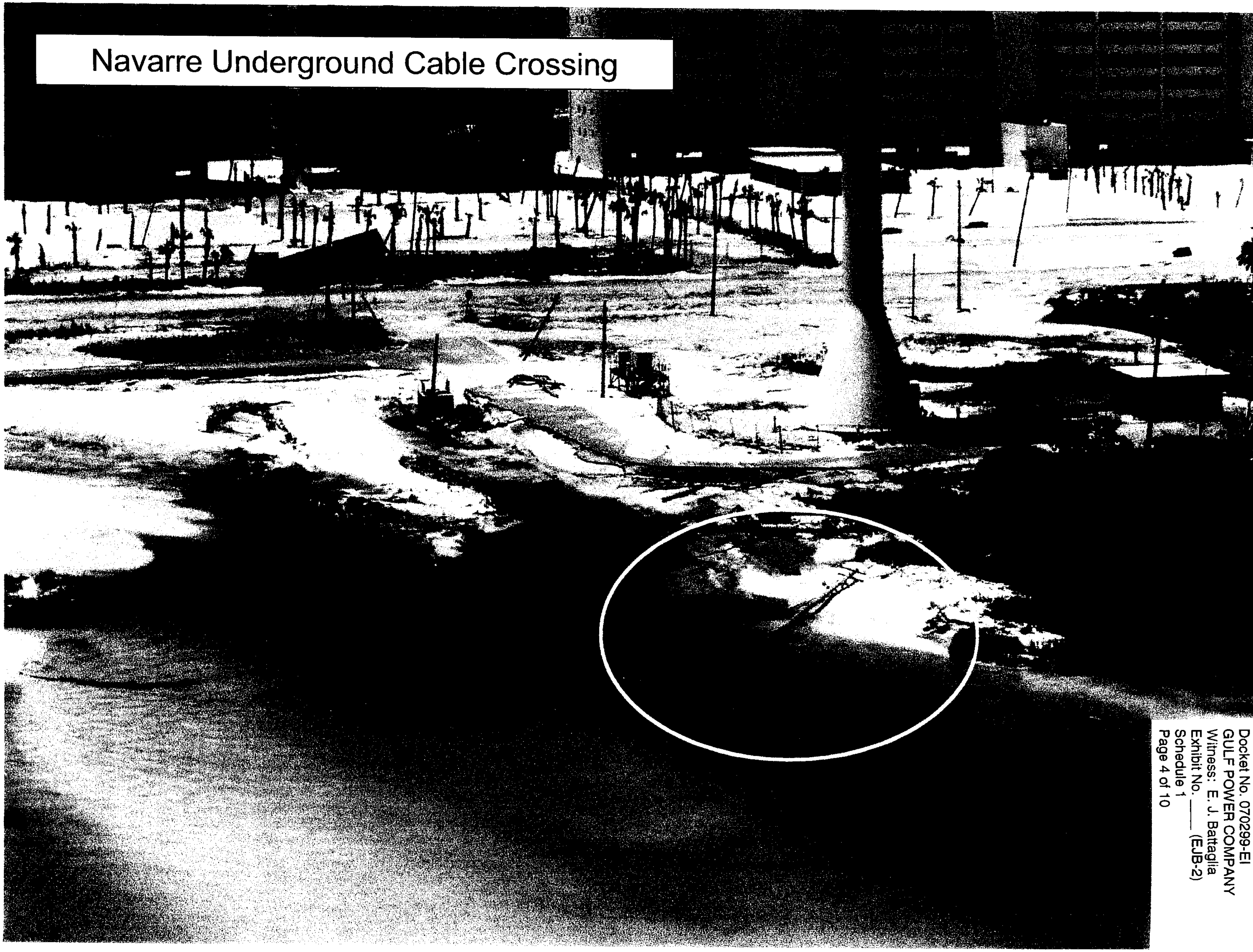
Destroyed Underground Switching Cabinet





Florida Public Service Commission
Docket No. 070299-EI
GULF POWER COMPANY
Witness: E. J. Battaglia
Exhibit No. ___ (EJB-2)
Schedule 1
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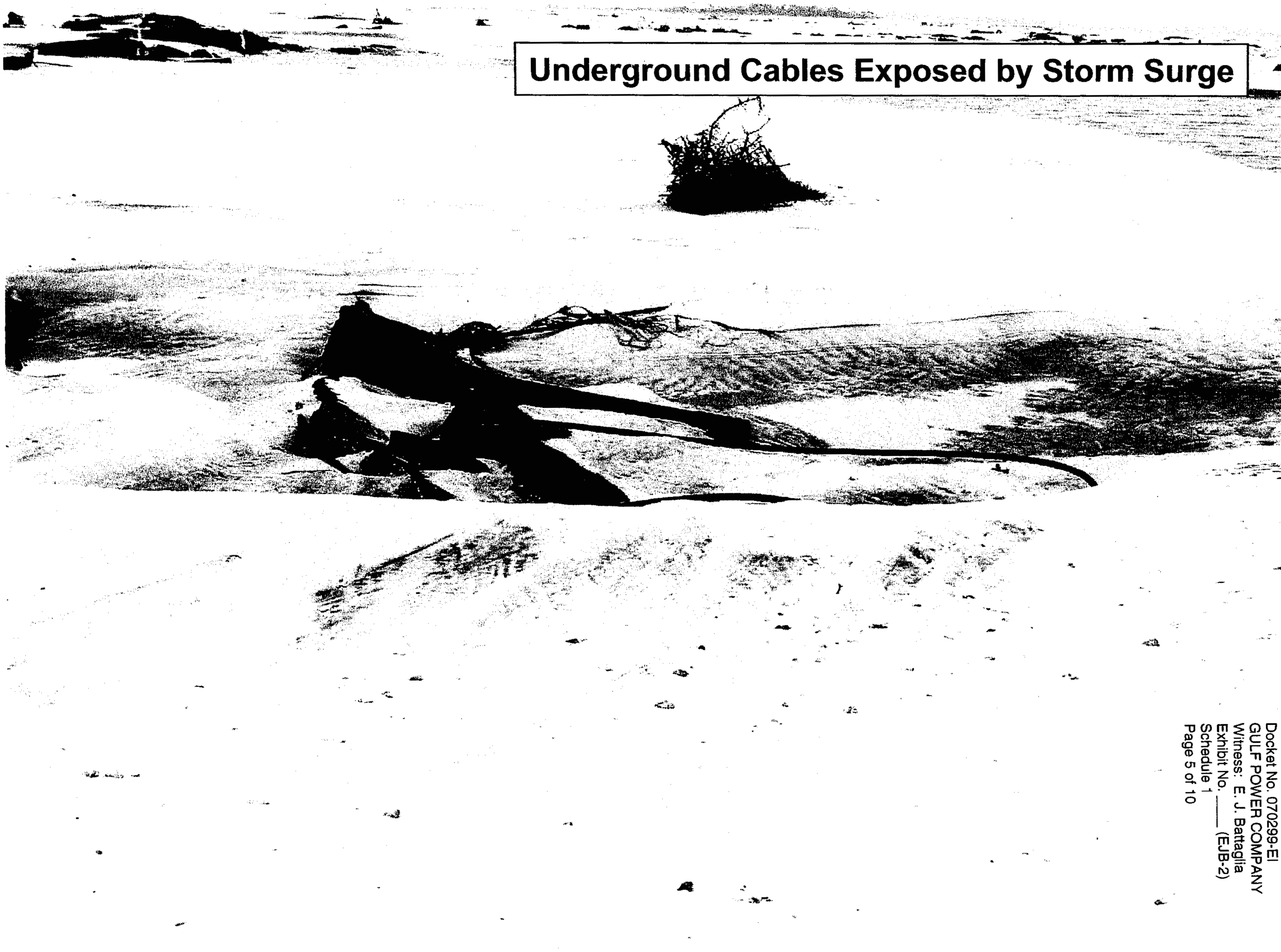
Underground Cables Exposed by Storm Surge



Florida Public Service Commission
Docket No. 070299-EI
GULF POWER COMPANY
Witness: E. J. Battaglia
Exhibit No. ____ (EJB-2)
Schedule 1
Page 5 of 10

Road Destroyed on Barrier Island

Florida Public Service Commission
Docket No. 070299-EI
GULF POWER COMPANY
Witness: E. J. Battaglia
Exhibit No. ____ (EJB-2)
Schedule 1
Page 6 of 10

HURRICANE OPAL 1995

- **There was a cul-de-sac here; now it's a canal. Our equipment is underwater.**

Florida Public Service Commission
Docket No. 070299-EI
GULF POWER COMPANY
Witness: E. J. Battaglia
Exhibit No. ____ (EJB-2)
Schedule 1
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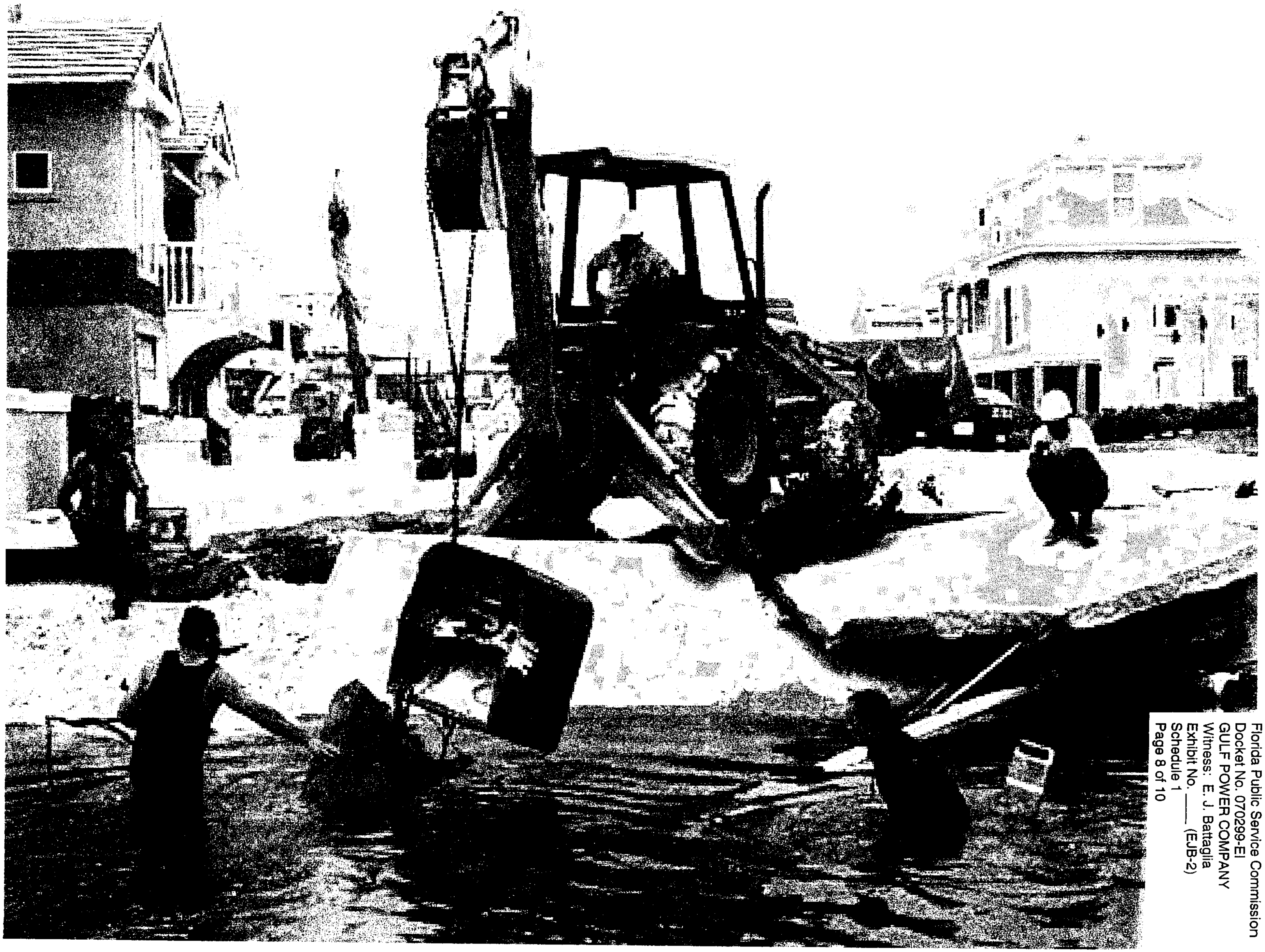

Florida Public Service Commission
Docket No. 070299-EI
GULF POWER COMPANY
Witness: E. J. Battaglia
Exhibit No. ____ (EJB-2)
Schedule 1
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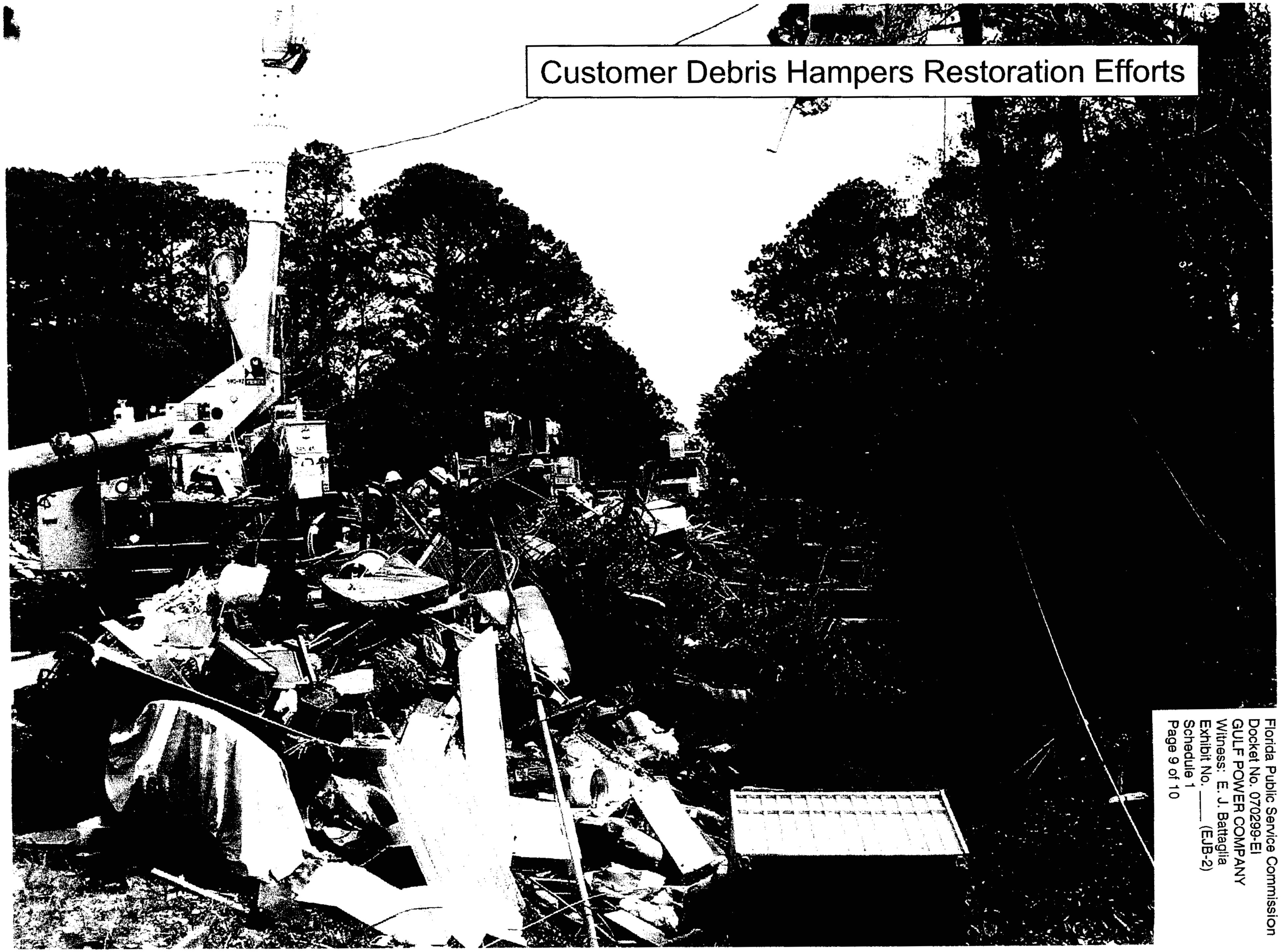
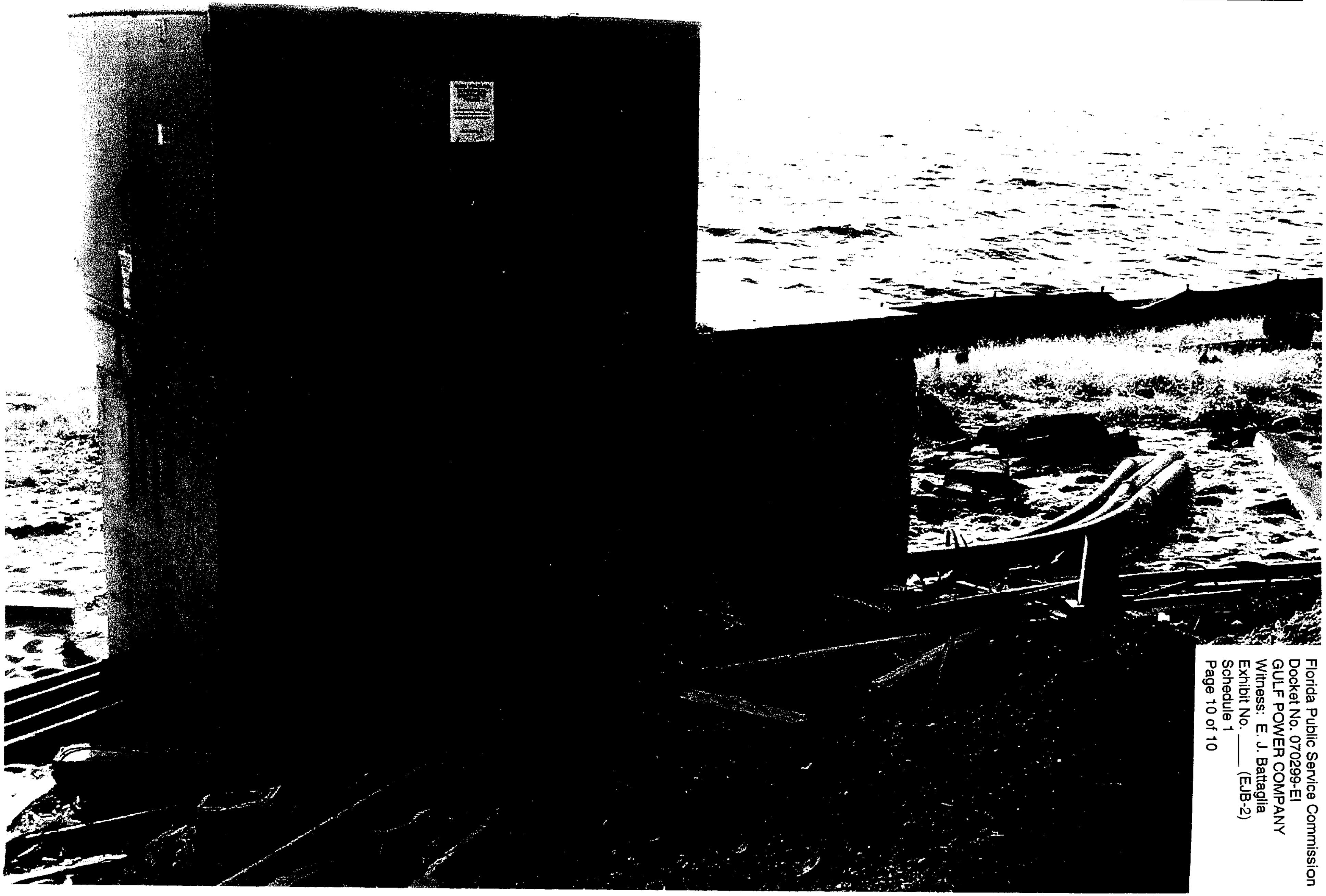


Florida Public Service Commission
Docket No. 070299-EI
GULF POWER COMPANY
Witness: E. J. Battaglia
Exhibit No. ____ (EJB-2)
Schedule 1
Page 9 of 10

Erosion around Padmount Switchgear



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Schedule 1
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Utility	Customers	Miles of line	Overhead Miles	Underground Miles
City of Washington	12,000	350	297	53
City of Kinston	12,400	450	N.A.	N.A.
Gulf Power Company	427,000	7,200	5,800	1,400

Preliminary Report
Hurricane Fran
23 August - 8 September 1996

Max Mayfield
National Hurricane Center
10 October 1996

Colorized infrared image of Hurricane Fran as part of a triple tropical cyclone outbreak. (98K GIF)

Colorized infrared image of Hurricane Fran near peak intensity east of the northern Bahamas and Florida. (87K GIF)

Fran was a Cape Verde hurricane that moved across the Atlantic during the peak of the hurricane season. It made landfall on the North Carolina coast as a category three hurricane on the Saffir/Simpson Hurricane Scale, resulting in significant storm surge flooding on the North Carolina coast, widespread wind damage over North Carolina and Virginia, and extensive flooding from the Carolinas to Pennsylvania.

a. Synoptic History

Hurricane Fran formed from a tropical wave that emerged from the west coast of Africa on 22 August. Deep convection associated with the wave was organized in a banding-type pattern and animation of satellite images suggested a cyclonic circulation. Ship reports soon confirmed that the circulation was on the surface. The post-analysis "best track" in Figure 1 (86K GIF) shows that the system became a tropical depression just southeast of the Cape Verde Islands at 1200 UTC 23 August. Best track position, central pressure and maximum one-minute sustained wind speed are listed for every six hours in Table 1.

The tropical depression moved westward near 15 knots for the next few days without significant development. This lack of development may be attributed, in part, to disrupted low-level inflow due to the large and powerful Hurricane Edouard which was centered about 750 n mi to the west-northwest. Satellite intensity estimates suggest that the depression became Tropical Storm Fran at 1200 UTC 27 August while located about 900 n mi east of the Lesser Antilles.

Fran began to track toward the west-northwest in the wake of Hurricane Edouard. Deep convection became more concentrated and Fran is estimated to have reached hurricane status at 0000 UTC 29 August while centered about 400 n mi east of the Leeward Islands. The center of Fran was about 150 n mi to the northeast of the Leeward Islands near 1200 UTC 30 August.

The tropical cyclone weakened to just below hurricane strength later on the 30th, possibly due to the low-level inflow being disrupted again by Edouard. About this time, changing steering currents caused Fran to turn toward the northwest and slow to about 5 knots.

By 1200 UTC 31 August, as Edouard moved farther away, Fran had regained hurricane strength. As Hurricane Edouard moved northward off the U.S. mid-Atlantic coast, the subtropical ridge became better established to the north of Fran, causing Fran to resume a west-northwestward motion with an increased forward speed of about 10 knots. Fran moved on a track roughly parallel to the Bahama Islands with the eye remaining a little more than 100 n mi to the northeast of the islands.

Fran strengthened to a category three hurricane by the time it was northeast of the central Bahamas on 4 September. The powerful tropical cyclone began to be influenced by a cyclonic circulation centered over Tennessee that was most pronounced in mid to upper levels of the atmosphere. Fran was steered by the resulting flow around the low over Tennessee and the western extension of the subtropical ridge over the northwest Atlantic. The hurricane gradually turned toward the northwest to north- northwest and increased in forward speed.

The minimum central pressure dropped to 946 mb and maximum sustained surface winds reached 105 knots, Fran's peak intensity, near 0000 UTC 5 September when the hurricane was centered about 250 n mi east of the Florida east coast.

Fran was moving northward near 15 knots when it made landfall on the North Carolina coast. The center moved over the Cape Fear area around 0030 UTC 6 September, but the circulation and radius of maximum winds were large and hurricane force winds likely extended over much of the North Carolina coastal areas of Brunswick, New Hanover, Pender, Onslow and Carteret counties. At landfall, the minimum central pressure is estimated at 954 mb and the maximum sustained surface winds are estimated at 100 knots. The strongest winds likely occurred in streaks within the deep convective areas north and northeast of the center.

Fran weakened to a tropical storm while centered over central North Carolina and subsequently to a tropical depression while moving through Virginia. The tropical cyclone gradually lost its warm core as it moved over the eastern Great Lakes and became extratropical near 0000 UTC 9 September while centered over southern Ontario. The remnants of Fran were absorbed into a frontal system near 0600 UTC 10 September.

b. Meteorological Statistics

Figures 2 (57K GIF) and 3 (78K GIF) show the curves of minimum central sea-level pressure and maximum one-minute "surface" wind speed, respectively, as a function of time. The observations on which the curves are based are also plotted and consist of aircraft reconnaissance data and Dvorak-technique estimates using satellite imagery, as well as synoptic fixes after landfall. According to international agreements within the world meteorological community, the surface wind is actually the wind representative of 33 feet (10 meters) above the ground.

All operational aircraft reconnaissance flights into Fran were provided by the U.S. Air Force Reserves. These "Hurricane Hunters" made 71 center fixes during 17 flights. The minimum central pressure reported by aircraft was 946 mb at 2306 UTC 4 September. A circular eye with a diameter of 25 n mi was observed on aircraft radar at this time. The 946 mb minimum pressure was measured by dropsonde and was the lowest pressure reported during Fran's existence. The maximum winds of 114 knots from a flight level of 700 mb (near 10,000 feet) were measured about 6 hours prior to the 946 mb pressure report. Flight-level winds in excess of 100 knots were reported several times during the two days prior to landfall. 113-knot winds were reported from aircraft 52 n mi east of the hurricane center at 2314 UTC 5 September, and 107-knot winds were reported 41 n mi northeast of the center at the time of landfall. However, the core of the hurricane weakened somewhat on radar presentations, and a closed eyewall was not reported by aircraft during the two hours prior to the center moving onshore.

Objective intensity estimates from digital infrared satellite imagery peaked near the time that the minimum central pressure was reported by reconnaissance aircraft.

The WSR-88D (Weather Surveillance Radar - 1988 Doppler) at Wilmington, North Carolina, measured winds in excess of 120 knots aloft as the inner convective bands approached the Cape Fear area at 2130 UTC 5 September.

A ship with call sign **LAVX4** reported 85 knot winds and a pressure of 984 mb at 1800 UTC 5 September while located about 60 n mi northeast of the hurricane center. Several other ship reports were helpful in defining the extent of tropical storm force winds, as were reports from a network of drifting buoys deployed offshore of the Carolinas in advance of Fran. Table 2 lists ship reports of at least tropical storm force winds in the vicinity of Fran.

Several wind gusts to hurricane force were measured from coastal areas in North Carolina. As usual for landfalling hurricanes, however, reports of sustained hurricane force winds are difficult to find. Table 3 lists selected U.S. surface observations. The NOAA C-MAN station at Frying Pan Shoals (about 50 n mi south-southeast of Wilmington, North Carolina) reported sustained winds of 79 knots and gusts to 108 knots from a tower about 80 feet above sea level.

Numerous pressure and wind reports from North Carolina were relayed to the NHC through amateur radio volunteers. The lowest measured pressure was 954 mb from Southport. The highest measured wind gust was 119 knots at an elevation of 30 feet (mounted on a house approximately 4 feet above the chimney) from a Davis wind instrument located on Hewletts Creek in Wilmington. A gust to 109 knots was measured in Wrightsville Beach. Although these measurements are very much desired to supplement the more official observations, they will not be listed in Table 3 until their accuracy is verified.

Several tornadoes were indicated by Doppler radar in North Carolina and Virginia. Confirmation, however, has been difficult due to the extensive nature of straight line wind damage across the region.

At the time of this report, a post-storm high water mark survey was being conducted by the U.S. Army Corps of Engineers and the U.S. Geological Survey. Many high water marks remain to be surveyed and "tied into" bench marks. The locations of the maximum values cannot be finalized until the survey is complete. However, initial survey results show an extensive storm surge along the North Carolina coast primarily southwest of Cape Lookout. Still water mark elevations on the inside of buildings, indicative of the storm surge, range from 8 to 12 feet. Outside water marks on buildings or debris lines are higher due to the effect of breaking waves.

Rainfall totals exceeding six inches were common near the path of Fran. WSR-88D radar precipitation estimates were as high as 12 inches over portions of Brunswick and Pender counties in North Carolina. Extensive flooding spread well inland from the Carolinas into Virginia, West Virginia and Pennsylvania. Some of this flooding was considered the most severe in years. Near Washington, D.C., for example, the Old Town district of historic Alexandria was partially evacuated as the Potomac River rose, flooding streets with more than three feet of water. The next update of this report will include an analysis of rainfall along the path of Fran to be provided by the NWS Eastern Region Headquarters.

c. Casualty and Damage Statistics

According to Associated Press reports, Hurricane Fran was responsible for 34 deaths. Most of the deaths were caused by flash flooding in the Carolinas, Virginia, West Virginia and Pennsylvania. Twenty-one died in North Carolina alone. However, the total death count will likely be revised downward in the next update of this report based on data from NWS personnel to be published in Storm Data, since the NWS attempts to list deaths **directly** attributable to the weather. For example, most vehicle accidents and heart attacks from over-exertion after a hurricane are not considered direct deaths.

Storm surge on the North Carolina coast destroyed or seriously damaged numerous beachfront houses. Widespread wind damage to trees and roofs, as well as downed power lines, occurred as Fran moved inland over North Carolina and Virginia. Extensive flooding was responsible for additional damage in the Carolinas, Virginia, West Virginia, Maryland, Ohio and Pennsylvania.

Nearly a half-million tourists and residents were ordered to evacuate the coast in North and South Carolina. Press reports from Reuters News Service stated that 4.5 million people in the Carolinas and Virginia were left without power.

The Property Claim Services Division of the American Insurance Services Group reports that Fran caused an estimated $1.6 billion dollars in insured property damage to the United States. This estimate includes $1.275 billion in North Carolina, $20 million in South Carolina, $175 million in Virginia, $50 million in Maryland, $20 million in West Virginia, $40 million in Pennsylvania and $20 million in Ohio. A conservative ratio between total damage and insured property damage, compared to past landfalling hurricanes, is two to one. Therefore, the total U.S. damage estimate is $3.2 billion.

d. Forecast and Warning Critique

During Fran's life as a tropical storm or hurricane, the average official track forecast errors ranged from 66 n mi at 24 hours (37 cases) to 137 n mi at 48 hours (33 cases) to 185 n mi at 72 hours (29 cases). These errors are at least 25 percent less than the previous ten-year averages of the official track errors.

The BAMD (deep-layer Beta and Advection Model) and the GFDI (interpolated version of the Geophysical Fluid Dynamics Laboratory model) provided the best guidance in terms of the lowest track forecast errors. However, the GFDI model showed a distinct bias to the left of the actual track (Figure 4) (77K GIF). The guidance from this model, which is generally acknowledged to be the most accurate one operationally available to the NHC, resulted in some left bias in the official forecasts near landfall.

Most NHC intensity forecast errors were 15 knots or less. All but one intensity forecast made after 2100 UTC 02 September correctly indicated a landfalling category three hurricane.

Table 4 lists the various watches and warnings that were issued. Hurricane warnings were posted for the hardest hit portions of the North Carolina coast about 27 hours prior to landfall.

Acknowledgments

Some of the information in this report was provided by NWS offices in the Eastern Region and is greatly appreciated. Stephen Baig prepared Fig. 1, and Mike Hopkins assisted with Table 3.

Table 1. Best track, Hurricane Fran, 23 August - 8 September, 1996

Date/Time (UTC)	Position		Pressure (mb)	Wind Speed (kt)	Stage
	Lat. (° N)	Lon. (° W)			
23/1200	14.0	21.0	1012	25	tropical depression
1800	14.1	22.8	1011	25	"
24/0000	14.2	24.8	1010	25	"
0600	14.2	26.6	1009	30	"
1200	14.1	28.2	1009	30	"
1800	14.1	29.6	1009	30	"
25/0000	14.1	30.8	1009	25	"
0600	14.3	32.0	1009	25	"
1200	14.6	33.4	1009	25	"
1800	14.7	35.1	1009	25	"
26/0000	14.9	37.0	1009	25	"
0600	15.1	38.6	1009	25	"
1200	15.3	40.0	1009	30	"
1800	15.2	41.4	1008	30	"
27/0000	14.9	42.7	1007	30	"
0600	14.7	43.8	1006	30	"
1200	14.6	[illegible]	[illegible]	35	tropical storm
1800	[illegible]	[illegible]	[illegible]	40	
28/0000	14.6	47.5	[illegible]	45	"
0600	[illegible]	[illegible]	[illegible]	50	"
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	"

29/0000	16.4	53.7	987	65	hurricane
0600	17.0	55.0	987	65	"
1200	17.8	56.3	988	65	"
1800	18.6	57.5	988	65	"
30/0000	19.1	58.5	991	65	"
0600	19.4	59.4	991	65	"
1200	19.8	60.1	989	65	"
1800	[illegible]	[illegible]	990	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
1200	21.1	61.4	984	65	hurricane
1800	21.5	61.7	983	65	"
01/0000	21.7	62.1	978	65	"
0600	21.9	62.6	982	65	"
01/1200	22.2	63.2	982	70	"
1800	22.5	63.9	981	75	"
02/0000	22.9	64.7	978	75	"
0600	23.3	65.7	976	75	"
1200	23.6	66.7	976	75	"
1800	23.9	67.9	976	75	"
03/0000	24.2	69.0	977	75	"
0600	24.4	70.1	975	80	"
1200	24.7	71.2	973	80	"
1800	25.2	72.2	968	85	"
04/0000	25.7	73.1	961	95	"
0600	26.4	73.9	953	100	"
1200	27.0	74.7	956	105	"
1800	27.7	75.5	952	105	"
05/0000	28.6	76.1	946	105	"
0600	29.8	76.7	952	105	"
1200	31.0	77.2	954	100	"
1800	32.3	77.8	952	100	"
06/0000	33.7	78.0	954	100	"
0600	35.2	78.7	970	65	"
[illegible]	[illegible]	79.0	985	40	[illegible]
1800	38.0	79.4	995	30	tropical depression
07/0000	39.2	79.9	1000	30	"
0600	40.4	80.4	1001	30	"
1200	41.2	80.5	1001	30	"
1800	42.0	80.4	1000	30	"
08/0000	42.8	80.1	999	30	"
0600	43.4	79.9	999	30	"
1200	44.0	79.0	1000	25	"
1800	44.5	77.6	1001	25	"
09/0000	44.9	75.9	1002	25	extratropical
0600	45.4	74.0	1004	20	"
1200	45.7	72.3	1006	15	"
1800	46.0	71.1	1008	15	"
10/0000	46.7	70.0	1010	15	"
0600					absorbed by a front

05/0000	28.6	76.1	946	105	**minimum pressure**
06/0030	33.9	78.7	954	100	**landfall near Cape Fear, NC**

Table 2. Ship reports of 34 knots or higher wind speed, associated with Hurricane Fran, August-September 1996.

date/time (UTC)	ship name	latitude (°N)	longitude (°W)	wind dir/ speed (knots)	pressure (mb)
30/0000	**AMAGISAN**	24.7	58.1	[illegible]	1017.0
30/0600	**AMAGISAN**	23.9	57.1	[illegible]	1015.0
30/1200	**AMAGISAN**	23.1	55.9	[illegible]	1015.0
30/1800	**AMAGISAN**	22.1	54.7	[illegible]	1014.0
31/0000	**AMAGISAN**	21.2	53.5	[illegible]	1014.5
31/0600	**AMAGISAN**	20.3	52.3	[illegible]	1014.0
31/1200	**SHIP**	26.7	60.8	[illegible]	1014.3
03/0600	**SEALAND CRUSADER**	26.8	67.3	[illegible]	1011.0
04/0000	**ELSX2**	28.4	74.6	[illegible]	1008.5
05/1200	**KAAPGRACHT**	32.2	79.6	010/66	1006.5
	LAVX4	32.9	76.7	[illegible]	1001.0
	ELRV2	32.9	77.4	[illegible]	1004.0
	SUNBELT DIXIE	33.2	77.3	[illegible]	1004.5
	CR MARSEILLE	33.6	77.1	[illegible]	1006.5
	CRISTOFORO COLOMBO	34.7	74.2	[illegible]	1013.0
05/1500	**LAVX4**	32.8	76.8	[illegible]	994.5
	ELRV2	33.2	76.7	[illegible]	1000.5
05/1800	**LAVX4**	33.0	76.9	100/85	984.0
	CR MARSEILLE	34.5	75.6	[illegible]	1007.0
05/2100	**CRISTOFORO COLOMBO**	33.0	73.6	[illegible]	1010.0
	ZIM AMERICA	34.7	74.0	[illegible]	1010.0
	OOCL FIDELITY	35.8	74.0	[illegible]	1012.0
06/0000	**COPACABANA**	31.5	72.9	[illegible]	1013.0
	CRISTOFORO COLOMBO	32.5	74.2	[illegible]	1010.0
	ZIM AMERICA	34.3	74.1	[illegible]	1009.0
	OOCL FIDELITY	35.4	74.2	[illegible]	1010.0
06/0300	**OOCL FIDELITY**	35.0	74.7	[illegible]	1007.0

06/0600	LAVX4	33.3	76.2	[illegible]	1006.0
	CR MARSEILLE	33.9	73.5	[illegible]	1013.2
06/0900	ZIM AMERICA	33.6	75.4	[illegible]	1009.0

Table 3. Hurricane Fran selected surface observations, September, 1996.

ocation	Press. (mb)	Date/time (UTC)	Sustained wind (kt) [a]	Peak gust (kt)	Date/time (UTC) [b]	Storm surge (ft) [c]	Storm tide (ft) [d]	Storm total rain (in.)
outh Carolina								
harleston (CHS)	998.0	05/2234	27	[illegible]	05/2330			1.10
harleston ity Office			29	[illegible]	05/1850	1.1		0.87
Cheraw	992.2			[illegible]	06/0315			1.32
erry Grove Pier				67	05/2215			8.36
Conway				[illegible]				5.02
Dillon								4.62
Florence			30 [M]	[illegible]	06/0250			2.21
arden City Pier				64	05/2215			5.91
Loris				[illegible]				5.14
Marion								3.01
Mullins								3.98
rtle Beach Pavilion				66	05/2215			
rtle Beach Pier				65	05/2215	3.6		7.02
orth Carolina								
pex (South RDU)								6.06
Atlantic Beach				87				
Butner								6.21
pe Lookout	987.0							
herry Point A (NKT) [M]	993.9	06/0255	[illegible]	66	06/0255			
Duck Pier						1.5		
uke Marine Lab Beaufort)				80		5.4		
zabeth City G (ECG)	1005.1	06/1147	[illegible]	[illegible]	06/1255			
ayetteville (FAY)	971.6	06/0430	[illegible]	69	06/0430			
gure Eight Island							10-12 [e]	
ort Bragg (FBG)	972.3	06/0246	[illegible]	64	06/0431			4.70
Graham								6.65
reensboro	984.4	06/0900	30	[illegible]	06/0537			3.91

(GSO)								
;reenville				87				
lden Beach				[illegible]	05/2300			
lew River	982.0	05/0230		82				7.05
Newport								3.24
ırth Topsail Beach			65		05/0045		8-9 [e]	
·egon Inlet						2.3		
'ope AFB (POB)	977.6	06/0455	[illegible]	[illegible]	06/0418			6.72
Raleigh-Durham (RDU)	977.6	06/0653	[illegible]	69	06/045			8.80
ıcky Mount (RWI) *	980.7	06/0200	17	[illegible]	06/0445			3.68
ıugemount urham Co)								6.02
Seymour Johnson (GSB)	981.0	06/0555	[illegible]	70	06/0555			6.38
Southport State Pilot Office				91				
/ilmington (ILM)	961.4	06/0036	[illegible]	75	05/2349			
/ilmington de Gauge						5.5		
/rightsville Beach							10-11 [e]	
OAA Ship **Whiting** [f]	959.9	05/2135						
rginia								
arlottesville (CHO) [M]	998.6	06/1645	22	[illegible]	06/1045			
Danville (DAN) [M]	987.5	06/1151	[illegible]	[illegible]	06/0449			
ot Springs (HSP) [M]	1002.4	06/1400	29	[illegible]	06/1540			
ynchburg (LYH) [M]	990.6	06/1454	18	[illegible]	06/1243			
ırfolk NAS (NGU)	1004.6	06/0855	[illegible]	[illegible]	06/0805	2.6		
Richmond (RIC)	1000.8	06/1141	32	[illegible]	06/1141			
Roanoke (ROA) [M]	994.7	06/1254	33	[illegible]	06/0954			
Staunton (SHD) [M]	997.6	06/1840	25	[illegible]	06/1120			
'ashington D.C. [g]						5.6/7.3		
IAN Stations								
rying Pan Shoals (FPSN7)	960.6	05/2300	79	108	05/2100			
Diamond Shoals (DSLN7)	1006.6	06/0500	[illegible]	65	06/0400			
pe Lookout (CLKN7)	996.9	06/0100	[illegible]	71	06/0300			

Folly Island (FBIS1)	997.6	05/2200	24		05/1900			

Florida Public Service Commission
Docket No. 070299-EI
GULF POWER COMPANY
Witness: E. J. Battaglia
Exhibit No. ____ (EJB-2)
Schedule 3
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[a] NWS standard averaging period is 1 min; ASOS and C-MAN are 2 min; buoys are 8 min.

[b] Date/time is for sustained wind when both sustained and gust are listed.

[c] Storm surge is water height above normal astronomical tide level.

[d] Storm tide is water height above NGVD.

[e] Estimated.

[f] Docked at Wilmington State Pier.

[*] Station not reporting from 02-10Z 06 Sept.

[M] Taken directly from METAR reports.

[g] The 5.6 ft value occurred on 06 Sept at 17 UTC, and was the actual storm surge, the 7.3 ft value occurred as a much broader peak on 09 Sept at 0418 UTC, from freshwater runoff.

Table 4. Watch and warning summary, Hurricane Fran, 23 August - 8 September, 1996.

Date/time (UTC)	Action	Location
29/0300	hurricane watch	Northeastern Leeward Islands from Antigua through St. Maartin
29/2100	hurricane watch discontinued	Northeastern Leeward Islands from Antigua through St. Maartin
	hurricane watch	Central Bahamas
	tropical storm warning	Central Bahamas
03/0900	hurricane watch	Northwestern Bahamas
03/1800	hurricane warning	Northwestern Bahamas
04/0300	hurricane watch	north of Sebastien Inlet, FL to Little River Inlet, SC
04/0900	watches and warnings discontinued	Central Bahamas
04/1500	hurricane watch extended northward	Little River Inlet, SC to Oregon Inlet, NC including Pamlico Sound
04/1800	hurricane warning downgraded to tropical storm warning	Northwestern Bahama Islands of Andros and New Providence
04/2100	hurricane warning	north of Brunswick, GA to Cape Lookout, NC
	hurricane watch	north of Cape Lookout, NC to Currituck Beach Light, NC including Pamlico and Albemarle Sounds
	tropical storm warning	Flagler Beach, FL to Brunswick, GA
	hurricane watch discontinued	south of Cape Lookout, NC
05/0300	hurricane warning extended northward	north of Cape Lookout, NC to NC/VA border including the Pamlico and Albemarle Sounds
	hurricane watch	north of NC/VA border to Chincoteague, VA including the Greater Hampton Roads area
	hurricane warning downgraded to tropical storm warning	northwestern Bahama Islands of Abaco and Grand Bahama
	hurricane warning discontinued	northwestern Bahama Islands
	tropical storm warning discontinued	Andros and New Providence Islands
05/0900	tropical storm warning discontinued	Flagler Beach, FL to Brunswick, GA
	tropical storm warning	northwestern Bahama Islands of Abaco and

Preliminary Report
Hurricane Bertha
05-14 July 1996

Miles B. Lawrence
National Hurricane Center
9 November 1996

PRELIMINARY REPORTS
Tropical Storm Arthur
Hurricane Bertha
Hurricane Cesar
Hurricane Dolly
Hurricane Edouard
Hurricane Fran
Tropical Storm Gustav
Hurricane Hortense
Hurricane Isidore
Tropical Storm Josephine
Tropical Storm Kyle
Hurricane Lili
Hurricane Marco

Bertha was an early-season Cape Verde Hurricane that moved across the islands of the northeastern Caribbean Sea as a category 1 hurricane on the Saffir/Simpson scale and made landfall on the North Carolina coast near Wilmington as a category 2 hurricane. Bertha's one-minute winds reached their maximum value of 100 knots on 9 July, while located to the north of Puerto Rico. The last Hurricane to reach this strength, this early in the season, was Alma in 1966 (117K GIF) in the eastern Gulf of Mexico with 110 knots. Bertha is responsible for an estimated eight deaths and $250 million in U.S. damages.

a. Synoptic History

Bertha originated from a tropical wave which moved from Africa to the Atlantic on 1 July. A weak circulation was first detected on satellite imagery on 3 July, centered about 500 n mi south of the Cape Verde Islands in the far eastern Atlantic Ocean. The track of the circulation center begins on 5 July, when the circulation is believed to have reached the surface and become a tropical depression, in the central tropical Atlantic. This track is displayed in Fig. 1 (102K GIF) and listed in Table 1.

Bertha followed a fairly smooth curved path around the western periphery of the Atlantic subtropical high pressure ridge. This ridge changed little during Bertha's existence and a weak mid-level trough persisted in the western North Atlantic. For three days, the depression moved toward the west-northwest at the fast forward speed of 20 to 25 knots and strengthened to a hurricane with 1-min. maximum sustained winds of 75 knots on the 8th as the center moved across the Leeward and Virgin Islands of the northeastern Caribbean. The center moved between Antigua and Barbuda at 0600 UTC on the 8th, across St. Barthelemy, Anguilla, and St Martin, just north of St.

Thomas, and over the British Virgin Islands by 1800 UTC.

The track gradually turned northwestward on the 9th and maximum sustained winds reached 100 knots at 0600 UTC. Bertha was centered 120 n mi north of Puerto Rico at this time, but earlier passed within 30 n mi of this island. The strongest winds were located in the northeast quadrant of the hurricane and most of Puerto Rico experienced only tropical storm conditions, except for Culebra, over which hurricane-force winds might have occurred.

Moving northwestward at a slower forward speed of 15 to 20 knots, the center of Bertha moved parallel to the Bahama islands, passing 40 to 60 n mi northeast of the Turks and Caicos islands, San Salvador, Eleuthera and the Abacos. Again, the strongest winds were located to the northeast of the center, but 65-knot sustained winds might have reached some of the above mentioned islands.

Continuing on its gradual turn, the track became north-northwestward on the 10th and 11th and the center moved parallel to the coast of Florida and Georgia at a distance of 150 to 175 n mi offshore. During this time, the forward speed slowed to about 8 knots. Moving northward and re-accelerating to a forward speed of 15 knots, Bertha made landfall at 2000 UTC on the 12th on the coast of North Carolina, with the center crossing the coast midway between Wrightsville and Topsail Beaches. The hurricane had been gradually weakening since its top speed of 100 knots on the 9th to 70 knots on the 11th. Then, in 12 hours just before landfall, the winds increased to 90 knots, which is the estimated maximum 1-min. wind speed at landfall. Bertha quickly dropped below hurricane strength when it moved inland over eastern North Carolina.

It then moved northeastward along the U.S. east coast, producing 40 to 60 knot sustained winds over land from northern North Carolina to New England and 60 knot winds over nearby Atlantic waters. Bertha was declared extratropical on the 14th when the center moved from the Maine coast to New Brunswick, Canada. The extratropical storm brought 40 to 50 knot winds to the Canadian Maritime Provinces and was tracked to just south of Greenland on the 17th.

b. Meteorological Statistics

Figures 2 and 3 (64K GIF) show a plot, versus time, of the various data used to estimate the minimum central sea-level pressure and the maximum 1-min. wind speed, 10 m above ground. Included are data from reconnaissance aircraft and satellite Dvorak-technique wind speed estimates. Table 2 lists selected surface observations of lowest pressure, peak wind, storm surge and rainfall values. Table 3 lists ship reports of 34 knots or greater that were associated with Bertha. The minimum pressure of 960 mb occurred at 0600 UTC on the 9th and is based on a dropsonde measurement. The best track maximum sustained wind speed of 100 knots at the same time is based on a 700-mb flight-level wind speed of 122 knots, measured 19 n mi east-northeast of the center.

Observations are incomplete from the Leeward and Virgin Islands, but because the circular eyewall was 20 - 30 n mi across, it is believed that hurricane conditions with sustained wind speeds to 75 knots, could have occurred on Antigua, Barbuda, Nevis, St. Eustatius, St. Bathelemy, Anguilla, St. Martin, and from St. Thomas northward through the U.S. and British Virgin Islands. Experience with Hurricane Marilyn in 1995 suggests that even higher sustained winds can occur over mountainous terrain as is found on many of these islands. Winds of 35 to 40 knots were experienced over portions of Puerto Rico as indicated by the San Juan observations in Table 2.

A reconnaissance aircraft flight level wind speed of 110 knots in the northeast quadrant of the circulation several hours before landfall is the basis for estimating sustained surface winds of 90 knots on the coast at landfall. The lowest sea-level pressure observed at landfall was 977 mb at Surf City, North Carolina and a value of 974 mb is assumed to be the minimum pressure at landfall.

Storm total rainfall amounts ranged from 5 to 8 inches along a coastal strip from South Carolina to Maine.

Coastal storm surge flood heights, from Florida through New England, ranged from 1 to 4 feet, but values to 5 feet were estimated on the North Carolina coast from Cape Fear to Cape Lookout. A storm surge of 6 feet or a little higher is indicated near Swansboro, where 5 to 6 feet of water was "inside of businesses on the waterfront".(from Newport, North Carolina National Weather Service Forecast Office Preliminary Storm Report).

Seven tornadoes have been confirmed, and these occurred during the passage of an outer rain band. There were five tornadoes in Virginia, one in North Carolina and one in Maryland.

c. Casualty and Damage Statistics

Twelve deaths have been related, in some way, to Hurricane Bertha. One, in Florida, was from an evacuating military jet crashing into a house. One death from an auto accident occurred in North Carolina and another drowned in rip currents. A surfer died in New Jersey. In Puerto Rico, two died in an automobile accident and another died while surfing. On the French half of St. Martin, one person was electrocuted and one fell off a boat.

The U.S. Virgin Islands, along with North Carolina, has been declared a federal disaster area. Surveys indicate that Bertha damaged almost 2500 homes on St. Thomas and St. John. For many, it was a second hit in the ten months since Hurricane Marilyn devastated the same area.

It is likely that there was beach erosion on the north coast of the Dominican Republic as Bertha passed to the north. The Bahamas were also affected by the weak side of the hurricane, but there are no damage figures available from either of these locations.

The primary effects in North Carolina were to the coastal counties and included storm surge flooding and beach erosion, roof damage, piers washed away, fallen trees, and damage to crops. A survey indicated over 5000 homes damaged, mostly from storm surge. A Federal Emergency Management Agency (FEMA) estimate of the number of persons in South and North Carolina who evacuated is 750,000. Minor wind damage and flooding also spread along the path of the storm all the way to New England.

The American Insurance Association reports an estimate of $135 million dollars in insured property damage, primarily along coastal North Carolina. A conservative ratio between total damage and insured property damage, compared to past land falling hurricanes, is two to one. Then the total U.S. damage estimate is 2 times $135 million or $270 million dollars. No figures are available from the Caribbean.

d. Forecast and Warning Critique

Bertha moved on a fairly smooth track. The average official track forecast errors for Bertha ranged from 80 n mi at 24 hours (32 cases) to 147 n mi at 48 hours (29 cases) to 224 n mi at 72 hours (27 cases). These errors are 15 per cent, or more, lower than the previous ten-year averages of the official track errors and are from 15 to 40 per cent lower than the CLIPER forecast errors for the same cases.

Overall, the track model guidance also performed very well. However, the 0000 UTC Aviation Model run on the 9th, when Bertha was located just north of Puerto Rico, (inexplicably?) showed the track recurving significantly further east than the previous run. All of the track guidance models that use the Aviation Model as a background environment also showed a similar track. This resulted in rather large official track forecast errors on the 9th, with a 613 n mi 72-hour error on the 1200 UTC forecast. The Aviation Model and some of the track guidance models recovered to an excellent forecast only 12 hours later. Fortunately, this guidance problem occurred three days prior to landfall in North Carolina and did not have a significant impact on U.S. warnings or on warnings for the Bahamas.

Table 4 lists the various watches and warnings that were issued. Hurricane warnings were issued from Sebastian Inlet, Florida to Chincoteague, Virginia as well as for the Bahamas and for the islands of the northeastern Caribbean Sea from Antigua through Puerto Rico. Tropical storm warnings were issued from Sebastian Inlet to north of Deerfield Beach, Florida and from north of Chincoteague to Watch Hill, Rhode Island. Almost all of the U.S. east coast was involved with some watch or warning and this is the result of the storm track's expected close passage to the southeast U.S. coast. The hurricane watch for the North Carolina landfall area was issued 65 hours before landfall and the hurricane warning was issued 47 hours before landfall. This is far more than the 36- and 24-hour lead times that the National Hurricane Center strives for and is the result of the forward motion decreasing at a faster rate than expected.

Table 1. Best track, Hurricane Bertha, 5 - 14 July, 1996 (updated 4 August 1996)

Date/Time	Position		Pressure	Wind Speed	Stage
	Lat.	Lon. (°			

(UTC)	(°N)	W)	(mb)	(kt)	
05/0000	9.8	34.0	1009	30	tropical depression
0600	10.2	36.3	1008	30	"
1200	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1800	[illegible]	[illegible]	[illegible]	[illegible]	
06/0000	[illegible]	[illegible]	[illegible]	[illegible]	
0600	[illegible]	46.8	[illegible]	35	
1200	[illegible]	[illegible]	[illegible]	40	
1800	[illegible]	[illegible]	[illegible]	45	
07/0000	[illegible]	[illegible]	[illegible]	50	
0600	[illegible]	[illegible]	[illegible]	55	
1200	[illegible]	56.3	[illegible]	60	
1800	16.5	58.4	992	70	hurricane
08/0000	17.0	60.1	988	75	"
0600	17.5	61.8	985	75	"
1200	18.0	63.5	983	70	"
1800	18.6	64.9	978	75	"
09/0000	19.4	66.1	970	80	"
0600	20.3	67.7	960	100	"
1200	21.4	69.4	965	100	"
1800	22.5	71.1	967	90	"
10/0000	23.6	72.6	969	85	"
0600	24.5	74.0	971	80	"
1200	25.4	75.3	968	80	"
1800	26.4	75.8	966	80	"
11/0000	27.5	76.4	968	75	"
0600	28.3	76.8	972	75	"
1200	29.2	77.5	977	75	"
1800	30.0	78.0	980	70	"
12/0000	30.7	78.3	982	70	"
0600	31.2	78.6	984	70	"
1200	32.2	78.4	975	85	"
1800	33.6	78.1	974	90	"
13/0000	35.0	77.6	993	65	"
0600	36.7	77.0	993	60	tropical storm
1200	38.1	76.1	994	[illegible]	
1800	40.3	[illegible]	991	60	
14/0000	42.1	71.9	994	60	
0600	44.1	69.0	995	55	
1200	46.0	66.0	995	50	extratropical
1800	47.0	62.0	995	50	"
15/0000	48.0	57.0	995	50	"
0600	49.0	52.0	996	45	"
1200	51.0	47.0	996	40	"
1800	54.0	44.0	996	40	"
16/0000	57.5	42.5	991	40	"
0600	58.5	42.5	988	40	"
1200	59.5	42.0	988	45	"
1800	59.8	41.0	985	45	"

17/0000	60.0	40.0	993	40	"
0600	60.5	39.0	1001	35	"
09/0600	20.3	67.7	960	100	**minimum pressure**
12/2000	34.3	77.8	974	90	**landfall * midway between Wrightsville and Topsail Beaches**

The eyewall also passed over Antigua, Barbuda, St. Barthelemy, Anguilla, St Martin, St Thomas, and the 3ritish Virgin Islands and passed close to a number of other islands in the northeastern Caribbean Sea.

Table 2. Hurricane Bertha selected surface observations, July 1996 (updated 20 August, 1997).

Location	Press. (mb)	Date/time (UTC)	Sustained wind (kt) [a]	Peak gust	Date/time (UTC) [b]	Storm surge (ft) [c]	Storm tide (ft) [d]	total rain (in.)
Antigua	991 [f]	08/0600	30 [f]	[illegible]	08/0400			
Florida:								
Jacksonville	1011.9	11/2256	22 (2 min)	27	11/1721			trace
Jacksonville Beach							2	
Georgia:								
Sea Island							3	
St. Simon							3	
South Carolina:								
Charleston Buoy (41004)	998.2	12/1200	[illegible]	[illegible]	12/0800			
Charleston city office			[illegible]	[illegible]	12/1130			0.94
Charleston harbor						2.7		
Charleston international airport	1008.5	12/1155	30 (2-min.)	39	12/0130			1.48
Cheraw								0.38
Cherry Grove pier			57	68				2.17
Folly Beach FBIS1 C-MAN	1006.8	12/1200	[illegible]	[illegible]	11/2100			
Garden City pier			[illegible]	[illegible]				1.01
Loris								2.77
Myrtle Beach	1003.7	12/1532	31	40	12/1512			2.40
Myrtle Beach, Sands Resort								4.73
Myrtle Beach Springmaid pier			[illegible]	[illegible]	12/1500	3.3		
Myrtle Beach pavilion			[illegible]	[illegible]				1.64

Summerville								1.40
North Carolina:								
Alligator River			[illegible]	[illegible]	13/0300			
Beaufort Duke marine lab				82	12/2200	2.8		
Beaufort (MRH)			[illegible]	[illegible]	12/2213			
Bath							6	
Bellhaven							7	
Bogue Field ASOS				71	13/0107			
Broad Creek								6.50
Brunswick							5	
Cape Lookout CLKN7 C-MAN (32 ft asl)	1002.0	12/2200	[illegible]	73	12/1837			
Carolina Beach							6	
Cherry Branch								5.09
Cherry Point (NKT)	995.7	12/2255	[illegible]	64	12/2304			
Diamond Shoals DSLN7 C-MAN (153 ft asl)	1007.7	13/0300	[illegible]	79	12/2345			
Duck DUCN7 C-MAN	1003.9	13/0500	[illegible]	[illegible]	13/0500			
East Wilmington				70				
Elizabeth City (ECG)	998.9	13/1313	[illegible]	[illegible]	13/0055			
Englehard			28 f	[illegible]	13/0300			
Fayetteville				[illegible]	12/2150			
Ft. Bragg				[illegible]	13/0055			
Frying Pan Shoals FPSN7 CMAN (145 ft asl)	977.5	12/1800	77 (10 min)	101	12/1610			
Greenville				76				4.11
Hatteras ASOS				[illegible]	12/2131			
Hatteras ferry ofice				[illegible]	13/0100			
Hatteras WSO	1007.1	13/0130		[illegible]	12/2243			
Holden Beach				70 f	12/1630			
Kure Beach			[illegible]	80	12/1835			
Lake Waccamaw								2.39
Lumberton (LBT)	1003.1	12/2156	26 (2-min)	33	12/2325			
Manteo			[illegible]	[illegible]	13/0345			

Newport	994.3	12/2200		78				2.95
New Bern				[illegible]	12/2208			4.56 [e]
New River (NCA)	980.8	12/2200	70	94	12/2021			
N Topsail Beach			67 [f]		12/2030			
Oregon Inlet			[illegible]	[illegible]	13/0300			
Pongo River							4.5	
Seymour Johnson AFB	986.3	12/2355	33	[illegible]	12/2155			4.03
Snow Hill								5.44
S. Pamlico River							3	
Southport (Nixon)	978.3	12/1835	[illegible]	74	12/1703			
Surf City (Horodner)	977	12/2005						
Swansboro							8	
Topsail Beach			68 [f]		12/2000			
Williamston								4.10
Wilmington (ILM)	978.7	12/2028	[illegible]	[illegible]	12/1902	1.3		5.66
Wilmnington (Armquist)	975.6	12/2000		[illegible]	12/2200			
Wilmnington, Fig. Eight Is.				83	12/1725			
Wilmington NC state port				77				
Wilmington port terminal	980.1	12/1850	from NOAA ship **Whiting**, 34.2N 77.96W					
Wrightsville Bch. Banks ch.				80				
Virginia:								
Cape Charles				[illegible]	13/0330			
Cape Henry			[illegible]	67	13/0600			
Chesapeake Bridge-Tunnel				[illegible]	13/0900			
Chesapeake Light Stn. CHLV2 C-MAN	998.9	13/0800	[illegible]	[illegible]	13/0700			
Eastville, Northhampton Co.								7.00
False Cape Buoy (44014)	1004.1	13/0900	[illegible]	[illegible]	13/0900			
Fenwick Is. Buoy (44009)	997.1	13/1400	[illegible]	[illegible]	13/1300			
Ft. Belvoir	1002.0	13/1055		[illegible]	13/1700			
Ft. Eustis	993.1	13/0755		[illegible]	13/0203			
Langley AFB	993.5	13/0755		[illegible]	13/0215			
Newport News (PHF)	993.1	13/0750	30	[illegible]	13/0228			
Norfolk								

International airport	995.1	13/0756	31		13/0740			2.44
Norfolk NAS (NGU)	994.4	13/0755	30		13/0155			
Norfolk, Sewells Point						2.5		
Oceana NAS (NTU)	997.2	13/0755			13/0615			
Pasquotank River							5	
Plantation Creek								7.20
Potomac river at Wisc. Ave.							5	
Wallops Island					13/0605			
Washington Dulles airport				29	13/1218			1.12
Washington National airport	1001.7	13/1221			13/0639			1.24
Willis Wharf, Accomac Co.								5.80
Maryland:								
Andrews AFB (ADW)	1000.6	13/1155			13/0750			0.94
Baltimore Washington airport	1000.3	13/1349			13/0704			2.28
Nanticoke, Wicomico Co.								5.03
Patuxent River NAS (NHK)	995.0	13/1100			13/0603			4.03
Salisbury	995.2	13/1240						5.62
Thomas Point TPLM2 C-MAN	998.8	13/1200	29		13/1700			
Delaware								
Cape Henlopen					13/1335			
Dover	995.6	13/1155	30					
Lewes					13/1250	1.58		
Wilmington	998.3	13/1451			13/2051			
New Jersey								
Atlantic City	994.9	13/1554			13/1111	2.27		2.41
Avalon					13/1409			
Estelle Manor								6.59
Harvey Cedars								
Millerville	995.2	13/1445			13/0950			
Newark airport	996.6	13/1909	25 (2-min.)		13/1521			
Teterboro airport	997.3	13/1945	26 (2-min.)		13/1547			
River Vale								2.17
West Milford								4.85

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Pennsylvania								
Philadelphia	997.5	13/1551	29					2.43
New York:								
Ambrose Light Tower ALSN6 C-MAN	994.5	13/1900			13/1500			
Babylon Village, L.I.				64				
Brookhaven airport			26		13/1947			
East Quogue, Suffolk co.								0.76
Farmingdale	995.3	13/2045						
Fire Is. Buoy (44025)	995.4	13/2000	33		13/1900			
Islip	994.8	13/2050	27		13/1557			
JFK airport	995.6	13/1942	31 (2-min.)		13/1458			
LaGuardia airport	995.9	13/1951	29 (2-min.)		13/1518			
Mt. Sinai (New York City)								2.49
Ossining, Westchester Co.								3.09
Pomona, Rockland Co.								4.65
Westhampton Beach	995.6	13/2045						
Connectucut:								
Bridgeport airport	995.5	13/2054	27		13/1547			
Danbury	996.3	13/2252						
Groton	995.9	13/2245						
Hartford	997.0	13/2245						
New Haven	995.6	13/2145						
Orange								
Preston				48				
Shelton								4.06
Vernon								5.50
Rhode Island:								
Fox Point hurricane barrier						2.1		
Sachuest Point (Middletown)				64	14/0010 ^{e} hand-held anemometer			
Providence	995.9	13/2336			13/1926			5.41
Massachusetts:								
Buzzards Bay Buoy (44028)	997.1	14/0000			14/0000			
Goshen								5.70
Billerica								7.20
Boston	996.3	14/0056						

New Bedford			[illegible]	76	13/2030	1.7		
Taunton ASOS	995.6	14/0041						
Puerto Rico:								
Lake Matrullas								3.02 [g]
Pueblito Del Rio								5.64 [g]
Quebrada Guava								6.84 [g]
Rio de la Plata								4.81 [g]
Rio Icacos								8.17 [g]
Rio Icacos Met Station								7.79 [g]
Rio Saliente								3.78 [g]
Roosevelt Roads	992.0	08/1930	[illegible]	[illegible]	08/1525			1.60
San Juan	996.8	08/2056	[illegible]	52	08/2110			1.56
St. Maarten	985.6	08/0935		70	08/0900-1000			
Virgin Islands:								
Bonne Resolution Gut, St. Thomas								1.44 [g]
Cane Bay, St. Croix							10-12	
Coral Bay, St. John								3.00 [g]
HESS Oil, St. Croix			[illegible]		08/1918			
Mt Zion, St. Thomas								3.28 [g]
Wintberg, St. Thomas								2.12 [g]

Averaging period is 1 min. unless otherwise indicated.
Date/time is for sustained wind when both sustained and gust are given.
Storm surge is water height above normal astronomical tide level.
Storm tide is water height above National Geodetic Vertical Datum.
Top of rain gage blew off and "a lot of rain was sucked out".
A more extreme value may have occurred.
24 hour total.

Table 3. Ship reports of 34 knots or higher wind speed, associated with Hurricane Bertha, July 1996.

date/time (UTC)	ship name	latitude (°N)	longitude (°W)	wind dir/ speed (knots)	pressure (mb)
07/1200	**FORT ROYAL**	17.1	53.8	110/39	1014.2

08/1800	MAYAGUEZ	21.6	64.3	[illegible]	1013.0
09/0000	SEALAND CONSUMER	21.6	64.7	[illegible]	1009.1
09/0300	MAYAGUEZ	20.0	64.6	[illegible]	1007.0
	SEALAND CONSUMER	21.0	65.0	[illegible]	1008.9
09/0600	MAYAGUEZ	16.9	65.1	[illegible]	1007.5
	SEALAND CONSUMER	20.6	65.1	[illegible]	1006.9
09/0900	SEALAND CONSUMER	20.4	65.3	[illegible]	1009.0
09/1800	SEALAND CRUSADER	23.0	67.9	[illegible]	1012.0
	CALAPATRIA	24.3	67.0	[illegible]	1013.2
11/1800	KIRF	27.8	77.8	[illegible]	1006.2
	SEALAND HAWAII	28.5	78.8	[illegible]	1006.0
	C6YC	29.6	73.5	[illegible]	1020.5
	NOBLE STAR	30.8	79.9	[illegible]	1010.0
	AALSMEERGRACHT	31.6	80.4	[illegible]	1010.0
	DSR EUROPE	32.4	72.6	[illegible]	1022.5
11/2100	C6YC	28.9	74.3	[illegible]	1018.8
12/0000	C6YC	28.3	74.8	[illegible]	1017.5
	NOBLE STAR	30.8	80.1	[illegible]	1004.7
	AALSMEERGRACHT	31.0	80.9	[illegible]	1010.0
12/0600	DSR EUROPE	30.7	74.7	[illegible]	1019.0
	AALSMEERGRACHT	31.1	80.6	360/66	1005.0
	SEALAND ATLANTIC	31.3	76.5	[illegible]	1008.0
12/0900	SEALAND ATLANTIC	30.8	76.4	[illegible]	1007.3
12/1200	BELGRAND	28.6	79.7	[illegible]	1015.5
	SEALAND ATLANTIC	30.4	76.4	[illegible]	1008.8
	ELSD9	30.9	75.4	[illegible]	1016.0
	SHIP	34.9	71.1	[illegible]	
12/1500	DSR EUROPE	30.0	77.3	[illegible]	1015.0
12/1800	DSR EUROPE	30.1	78.1	[illegible]	1015.5
	FENELLA	30.5	74.8	[illegible]	1013.0
	ELSD9	30.7	76.3	[illegible]	1017.5
	SHIP	32.7	73.6	[illegible]	1016.8
	ESSO CORAL GABLES	33.8	73.9	[illegible]	1017.8
	EXPORT PATRIOT	32.7	75.2	[illegible]	1022.2

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13/0000	**ESSO CORAL GABLES**	33.6	75.1	[illegible]	1012.2
13/0600	**KAIJIN**	32.2	73.7	[illegible]	1017.0
	ESSO CORAL GABLES	33.3	76.0	[illegible]	1013.3
13/1200	**ZIM CANADA**	39.3	73.9	[illegible]	1006.0
	BREMEN EXPRESS	37.9	73.2	[illegible]	1008.1
13/1500	**3FEB5**	36.5	69.9	[illegible]	1019.6
	BREMEN EXPRESS	37.6	73.9	[illegible]	1006.5
	ZIM CANADA	38.7	74.1	[illegible]	1000.0
13/1800	**3FEB5**	36.0	70.0	[illegible]	1017.9
	BREMEN EXPRESS	37.3	74.8	[illegible]	1009.6
	ZIM CANADA	38.1	74.3	[illegible]	1005.0
	SONG OF AMERICA	40.6	72.4	[illegible]	1004.0
13/2100	**PHAROS**	39.5	69.0	[illegible]	1012.6
14/0000	**PHAROS**	39.6	69.5	[illegible]	1009.8
	NJPJ	41.9	70.3	[illegible]	1006.1
14/0600	**PHAROS**	39.7	70.4	[illegible]	1013.3
14/0900	**A.S.L. SANDERLING**	45.0	60.4	[illegible]	1011.4
14/1200	**TRITONHIGHWAY**	37.4	66.5	[illegible]	1022.0
	ALFRED NEEDLER	43.3	62.6	[illegible]	1007.0
	KASUGA 1	43.9	61.3	[illegible]	1007.8
	A.S.L. SANDERLING	45.2	59.4	[illegible]	

Table 4. Watch and warning summary, Hurricane Bertha, July 1996.

Date/time (UTC)	Action	Location
06/1500	hurricane watch	Antigua, Barbuda, Nevis, Montserrat, St Kitts, Anguilla, Saba, St Eustatius, Dominica, and Dutch St Maarten
06/2100	hurricane watch	Guadeloupe, St Barthelemy, French St Martin, U.S. and British Virgin Islands
07/0300	hurricane warning	Dominica northward to Anguilla and St Maarten
07/1200	hurricane watch	Puerto Rico
07/1500	hurricane warning	U.S. and British Virgin Islands and Puerto Rico
08/0000	tropical storm watch	Dominican Republic from Isla Saona to Cabo Frances Viejo
08/0300	hurricane watch	Dominican Republic from Isla Saona to Cabo Frances Viejo
08/0900	hurricane watch	Turks and Caicos Islands
08/1200	hurricane warning	Dominican Republic from Cabo Caucedo to Monte Cristo, southeastern Bahamas
08/1500	hurricane warning discontinued	Dominica

	hurricane watch	Haiti from St Nicolas to border of Dominican Republic
08/1800	hurricane warning discontinued	Leeward Islands south and east of St Eustatius
08/2100	hurricane warning	Turks and Caicos Islands and southeastern Bahamas
	hurricane warning discontinued	Leeward Islands
	hurricane watch	central Bahamas
09/0100	hurricane warning discontinued	U.S. and British Virgin Islands
09/0300	hurricane warning discontinued	Puerto Rico
	tropical storm warning	Haiti from St Nicolas to border of Dominican Republic
09/0900	hurricane warning	central Bahamas
	hurricane watch	northwestern Bahamas
09/1500	watches and warnings discontinued	Dominican Republic and Haiti
09/2100	hurricane warning	northwestern Bahamas
10/0300	tropical storm warning	north of Deerfield Beach, FL to Brunswick, GA
	hurricane watch	north of Brunswick to NC/VA border including Pamlico and Albemarle Sounds
10/0900	hurricane warning discontinued	Turks and Caicos Islands and southeastern Bahamas
10/1500	hurricane warning	Sebastian Inlet, FL to Cape Romain, SC
10/1800	hurricane warning discontinued	central Bahamas
10/2100	hurricane warning	Cape Romain to NC/VA border including Pamlico and Albemarle Sounds
	tropical storm warning discontinued	south of Sebastian Inlet, FL
11/0300	hurricane watch	NC/VA border to Chincoteague VA including southern Chesapeake Bay
11/0600	hurricane warning discontinued	northwestern Bahamas
11/0900	hurricane warning discontinued	south of Brunswick, GA
12/0900	hurricane warning discontinued	Savannah, Ga southward
12/1500	tropical storm warning	NC/VA border to Chincoteague, VA including southern Chesapeake Bay
12/1900	hurricane warning discontinued	Cape Romain, SC southward
12/2100	hurricane warning	NC/VA border to Chincoteague, VA including the Hampton Roads area
	tropical storm warning	north of Chincoteague, VA to Watch Hill, RI including the lower Delaware Bay
	tropical storm watch	east of Watch Hill to the Merrimack River, MA
13/0300	hurricane warning discontinued	south of Topsail Beach, NC
	hurricane watch discontinued	lower Chesapeake Bay
	tropical storm warning	all of Chesapeake Bay and the lower tidal Potomac River and all of Delaware Bay
13/0700	hurricane warning to tropical storm warning	Topsail Beach, NC to Chincoteage, VA including Albemarle and Pamlico Sounds
13/0900	hurricane warning discontined	NC/VA border southward
13/1200	tropical storm warning discontinued	south of Fenwick Island, DE

13/1500	tropical storm warning discontinued	south of Brigatine, NJ and Delaware Bay
13/2100	tropical storm warning discontinued	south of Fire Island, NY
14/0000	tropical storm warning discontinued	south of Watch Hill, RI
14/0300	tropical storm warning discontinued	remainder of U.S east coast

ıber 28, 1998

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Preliminary Report
Hurricane Bonnie
19-30 August 1998

Lixion A. Avila
National Hurricane Center
24 October 1998

Bonnie was the third hurricane to directly hit the coast of North Carolina during the past three years.

a. Synoptic History

The origin of Bonnie was a large and vigorous tropical wave that moved over Dakar, Senegal on 14 August. The wave was depicted on visible satellite imagery by a large cyclonic low- to mid-level circulation void of deep convection. The wave caused a 24-h surface pressure change of -3.5 and -4.0 mb at Dakar and Sal respectively. There was a well established 700 mb easterly jet which peaked at 50 knots just before the wave axis crossed Dakar, followed by a well marked wind-shift from the surface to the middle troposphere. The overall circulation exited Africa basically just north of Dakar where the ocean was relatively cool. However, a strong high pressure ridge steered the whole system on a west-southwest track over increasingly warmer waters and convection began to develop. Initially, there were several centers of rotation within a much larger circulation and it was not until 1200 UTC 19 August that the system began to consolidate and a tropical depression formed. Although the central area of the tropical depression was poorly organized, the winds to the north of the circulation were nearing tropical storm strength. This was indicated by ship observations and high resolution low-cloud wind vectors provided in real time by the University of Wisconsin. The depression was then upgraded to Tropical Storm Bonnie based on these winds and satellite intensity estimates at 1200 UTC 20 August. Bonnie moved on a general west to west-northwest track around the circulation of the Azores-Bermuda High toward the northern Leeward Islands.

The first reconnaissance plane reached Bonnie late on the 20th and measured a minimum pressure of 1004 mb and winds of 61 knots at 1500 feet to the northeast of the center. Bonnie skirted the Leeward Islands and most of the associated weather remained to the north over the open Atlantic. During that period, Bonnie's circulation was very asymmetric.

Under a favorable upper-level wind environment, Bonnie gradually strengthened and became a hurricane at 0600 UTC 22 August when it was located about 200 n mi north of the eastern tip of Hispaniola. At that time, the hurricane hunters found a nearly complete eyewall and flight-level peak winds of 76 knots. Bonnie moved on a general west-northwest heading and reached maximum winds of 100 knots and a minimum pressure of 954 mb about 150 n mi east of San Salvador in the Bahamas.

The ridge to the north of Bonnie temporarily weakened and the steering currents collapsed. The hurricane then drifted northward for a period of 18 to 24 hours. Thereafter, the subtropical ridge reintensified, forcing Bonnie to move northwestward and then northward toward the coast of North Carolina while the hurricane maintained winds of 100 knots.

After a slight weakening, the eye of Bonnie passed just east of Cape Fear around 2130 UTC 26 August and then made landfall near Wilmington as a border line Category 2/3 hurricane on the Saffir/Simpson Hurricane Scale (SSHS) around 0330 UTC 27 August.

The hurricane slowed down and weakened while moving over eastern North Carolina. It was then downgraded to tropical storm status based on surface observations and WSR88-D winds. Bonnie turned northeastward over water ahead of a middle-level trough and rapidly regained hurricane strength as indicated by aircraft reconnaissance data. Thereafter, the hurricane moved on a general northeast to east track and became extratropical near 1800 UTC 30 August, about 240 n mi south southeast of New Foundland.

Bonnie's track is shown in Fig. 1 (50K GIF). Table 1 is a listing, at six-hourly intervals, of the best-track position, estimated minimum central pressure and maximum 1-minute surface wind speed.

b. Meteorological Statistics

The best track pressure and wind curves as a function of time are shown in Figs. 2 (25K GIF) and 3 (20K GIF) and are primarily based on data from numerous reconnaissance flights into the hurricane. The best track also incorporates WSR-88D data, surface observations and GPS sondes in the eyewall of the hurricane. The routine satellite intensity estimates from the Tropical Analysis and Forecast Branch (TAFB), the Satellite Analysis Branch (SAB) and the Air Force Weather Agency, (AFGWC in figures) were also included. The Hurricane Bonnie event was characterized by a high density of observations. During Bonnie, the NOAA high altitude jet and P-3 deployed a very large number of sondes over a large portion of the Atlantic as a part of a major synoptic flow experiment. These observations were primarily used to initialize the numerical models.

The maximum winds measured were 116 knots at the 700-mb level at 0113 UTC 25 August and then again at 1659 UTC 26 August. These measurements were taken during the AF963 and the NOAA 43 reconnaissance missions, respectively. Table 2 displays selected surface observations during Bonnie, primarily over the area where the hurricane made landfall. There were several important and useful observations relayed to the NHC and to the local NWS forecast offices from amateur observing reports. These include reports of peak winds of 104 knots at 0138 UTC near NC State Port and 100 knots at Wrightsville Beach at 1951 UTC 27 August. Rainfall totals of about 8 to 11 inches were recorded in portions of eastern NC.

Storm tides of 5 to 8 feet above normal were reported mainly in eastern beaches of Brunswick County NC, while a storm surge of 6 feet was reported at Pasquotank and Camdem counties in the Albemarle Sound.

A tornado was reported in the town of Edenton NC in Chowan County.

c. Casualty and Damage Statistics

Three people died as a consequence of Bonnie. A 12-year old girl was killed when a large tree fell on her home in Currituck County, NC. Another person was caught in rip currents and drowned in Rehoboth Beach, Delaware. The third person died in Cape Cod in a rowboat accident when choppy seas overturned the boat. The last one may have been indirectly related to Bonnie.

There are numerous reports of many trees down, roof and structural damage and widespread power outages primarily in eastern North Carolina and Virginia where a federal disaster was declared for several counties. The area hardest hit appears to have been Hampton Roads, Virginia, where the damage could reach well into the hundreds of millions of dollars.

The Property Claim Services Division of the American Insurance Services Group reports that Bonnie caused an estimated $ 360 million in insured property damage to the United States. This estimate includes $ 240 million in North Carolina, $ 95 million in Georgia, and $ 25 million in South Carolina. A conservative ratio between total damage and insured property damage, compared to past landfalling hurricanes, is two to one. Therefore, the total U.S. damage estimate is $ 720 million.

d. Forecast and Warning Critique

Figure 4 (26K GIF) shows a sequence of numerical guidance forecast track for 1800 UTC on 22, 23 and 24 August. Note that on the 22nd, most of the models suggested that Bonnie was going to remain out to sea. Thereafter, during the 23rd and 24th, there was a significant change in the model forecasts and some of them turned the hurricane toward the west while others kept it out to sea. At that point, the forecast became very difficult and highly uncertain. Consequently, watches and warnings were required for a large portion of the southeast U.S. coast (Table 3). In spite of the model's scatter, the official forecast tracks remained basically unchanged and in the middle of the model forecast ensemble. Apparently, during the earlier runs, the models weakened the ridge to the north of the hurricane too soon and forecast a premature recurvature.

Table 4 lists track forecast error statistics. The official forecast errors for Bonnie were in general very close to the most recent 10-year average. There was only a small improvement in the 48 and 72 hour forecast if compared to the average.

With the exception of a few 72-h forecast errors at the beginning of Bonnie's life, the NHC intensity forecasts for Bonnie were smaller than the past 10-year average errors.

Table 1. Best track, Hurricane Bonnie, 19- 30 August, 1998

Date/Time (UTC)	Position		Pressure (mb)	Wind Speed (kt)	Stage
	Lat. (° N)	Lon. (° W)			
19/1200	14.7	48.1	1009	25	tropical depression
1800	15.4	50.1	1009	30	"
20/0000	16.2	52.2	1009	30	"
0600	16.9	54.7	1008	30	"
[illegible]	[illegible]	[illegible]	1007	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

21/0000	[illegible]	[illegible]	[illegible]	[illegible]	
0600	[illegible]	62.8	1002	45	
1200	19.5	64.5	1000	[illegible]	"
1800	20.3	[illegible]	996	55	
22/0000	21.1	67.3	991	65	hurricane
0600	21.8	68.7	989	70	"
1200	22.3	69.8	980	75	"
1800	23.0	70.5	970	85	"
23/0000	23.4	71.0	962	90	"
0600	23.8	71.3	960	95	"
1200	24.1	71.5	958	100	"
1800	24.4	71.7	955	100	"
24/0000	24.8	71.8	954	100	"
0600	25.2	72.1	960	100	"
1200	25.6	72.4	962	100	"
1800	26.1	72.8	963	100	"
25/0000	26.9	73.2	963	100	"
0600	27.8	73.8	962	100	"
1200	28.8	74.7	963	100	"
1800	29.8	75.6	963	100	"
26/0000	30.8	76.4	958	100	"
0600	31.7	77.3	964	100	"
1200	32.7	77.8	965	100	"
1800	33.4	77.8	962	100	"
27/0000	34.0	77.7	963	95	"
0600	34.5	77.5	965	85	"
1200	34.9	77.1	974	75	"
1800	35.4	76.6	980	60	tropical storm
28/0000	35.8	75.9	983	65	hurricane
0600	36.2	75.1	985	75	"
1200	36.7	74.3	990	65	"
1800	37.3	73.2	991	60	tropical storm
29/0000	38.3	71.4	992	45	"
0600	39.2	69.6	993	45	"
1200	40.2	67.6	999	45	"
1800	41.6	64.8	1000	45	
30/0000	42.9	61.5	1000	45	"
0600	44.0	57.0	1000	45	"
1200	44.0	53.5	1000	45	"
1800	44.0	50.0	998	45	extratropical
31/0000	44.0	45.0	996	45	"
0600	43.0	41.0			absorbed by a front
24/0000	24.8	71.8	954	100	**minimum pressure**
27/0400	34.4	77.7	964	95	**Landfall near Wilmington NC**

Table 2. Hurricane Bonnie selected surface observations, August 1998.

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Location	Minimum sea-level pressure		Maximum surface wind speed (kt)					
	Pressure (mb)	Date/time (UTC)	Sustained wind (kts) [a]	Peak gust (kts)	Date/time[b] (UTC)	Storm surge[c] (ft)	Storm tide[d] (ft)	Rain (storm total) (in)
U.S.Virgin Islands								
St. Thomas Airport	1006.1	21/1128	23	33	21/0851			0.29
Puerto Rico								
Ceiba	1006.8	21/1121	24	33	21/0156			0.51
Carolina								1.10
Grand Turk Island								3.50
South Carolina								
Charleston International Airport	1007.0	26/1856	25	33	26/2034			
Charleston City Office			25	[illegible]	26/1230			
Myrtle Beach (MYR)			[illegible]	42	26/1715			
North Carolina								
Wilmington	969.9	27/0053	40	64	26/1827			9.04
Kure Beach				77	26/1630			
Florence Air.			34	44	26/2150			
Elizabeth City	995.7	28/0030	[illegible]	63	28/0333			1.42
Ocracoke	990.5	27/1815		66	27/1457			6.60
Oregon Inlet	989.1			54	27/2015			
Emerald Isle	976.9			62				
Newport	985.1	27/1030		52	27/0553			9.51
Greenville				69	27/0915			8.20
Morehead City								10.70
Cherry Point			[illegible]	61	27/0114			10.93
Jacksonville				52	27/1133			11.00
Frisco			49	69	27/1109			
New Hanover							7-9	
Tide Gage on Masonboro Isl.							9.1	
Wrightsville Beach							7- 7.3	
Virginia								
Cape Henry			70	90	28/0300			
Chesapeake Light Stn. Brookley Field			68	81	28/0350			
Currituck County EOC				81	28/0400			
Oceana NAS	999.0		[illegible]	54	28/0357			
Langley AFB	1005.0		[illegible]	[illegible]	27/2355			
Norfolk Airport (ORF)	1000.4	28/0024	[illegible]	58	28/0141			6.77
Porthmouth	1000.0	28/0105		[illegible]	28/0222			2.44

Norfolk NAS	1002.0		[illegible]	[illegible]	27/2315			4.91
Sewells Point							6.0	
Coastal Pasquotank						6.0		
Chowan County						5-6		
New Jersey/Delaware								
Delaware Light Buoy	1005.2	28/1800	32	[illegible]	28/1700			
Reedy Point							6.28	
Cape May							6.05	
Atlantic City							4.97	
Sandy Hook							5.64	
Georges Bank Buoy	990.2	29/1600	[illegible]	[illegible]	29/1700			
CMAN Stations								
Frying Pan Shoals (FPSN7)	964.0	26/1630	76[f]	90	26/2130			
Cape Lookout (CLKN7)	994.2	27/1300	[illegible]	75	27/1211			
Diamond Shoals (DSLN7)	996.8	27/2200	68	79	27/2034			
Duck NC (DUCN7)	993.5	28/0100	[illegible]	[illegible]	27/2000			
Cheasepeake Lt. (CHLV7)	995.7	28/0600	72[f]	86	28/0532			
Buoys								
41002	998.7	26/0300	[illegible]	[illegible]	26/0426			
41004	990.5	26/1300	[illegible]	[illegible]	26/1600			
44004	994.3	29/0600	[illegible]	[illegible]	29/0131			
44014	989.8	28/1000	[illegible]	[illegible]	28/0200			
44137	998.2	30/0000	[illegible]		30/0300			
44144	990.8	30/0300	[illegible]		30/0300			

Standard NWS ASOS and C-MAN maveraging period is 2 min; buoys are 8 min unless otherwise indicated.

Date/time is for sustained wind when both sustained and gust are listed.

Storm surge is water height above normal astronomical tide level.

Storm tide is water height above NGVD.

Estimated.

10 min average wind.

Table 3. Tropical Cyclone watch and warning summary for Hurricane Bonnie.

Date/time (UTC)	Action	Location
20/0300	Tropical Storm Watch issued	Antigua, Barbuda, Anguilla, St. Maarten, Saba and St. Eustatius
20/1500	Tropical Storm Watch issued	U.S. and British Virgin Islands
20/2100	Tropical Storm Warning issued	U.S. and British Virgin Islands
	Tropical Storm Watch issued	Puerto Rico

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21/0900	Tropical Storm Watch issued	Turk and Caicos and the southeastern Bahamas
21/1200	Tropical Storm Watch discontinued	Antigua, Barbuda, Anguilla, St. Maarten, Saba and St. Eustatius
21/1500	Tropical Storm Warning and a Hurricane Watch	Turk and Caicos and southeastern Bahamas
	Hurricane Watch issued	Central Bahamas
	Tropical Storm Warning discontinued	U.S. and British Virgin Islands
	Tropical Storm Watch discontinued	Puerto Rico
22/0900	Hurricane Warning issued	Central Bahamas
22/1500	Hurricane Watch issued	Northwestern Bahamas
23/0000	Hurricane Warning discontinued	Turks and Caicos
	Hurricane Warning replaced by Tropical Storm Warning	Southeastern Bahamas
24/0900	Tropical Storm Warning discontinued	Southeastern Bahamas
24/2100	Hurricane Watch issued	Savannah, Georgia to the North Carolina/Virginia border including the Pamlico and Albemarle Sounds
25/0900	Hurricane Warning issued	from Murrells Inlet, S.C. to the north Carolina Virginia border, including the Palmico and Albemarle Sounds
25/1200	Hurricane Watch issued	from North Carolina/Virginia border to Cape Henlopen, Delaware including the Chesapeake Bay southward from Windmill point.
25/1500	Tropical Storm Warning issued	from Murrels inlet to Cape Romain, S.C.
25/1800	Hurricane Warning extended northward	to Chincoteague, VA
25/2100	Hurricane Warning extended southward	to Cape Romain, S.C.
26/0600	Hurricane Warning extended southward	to Edisto Beach, S.C.
26/1500	Hurricane Warning and Watches discontinued	south of Cape Romain
26/2100	Hurricane Warnings and Watches revised. Tropical Storm Warning and Hurricane Watch issued	from North Carolina/Virginia border to Chincoteague, Virginia and for the Chesapeake Bay from Smith Point southward
	Tropical Storm Warning issued	from Chincoteague, Virginia to Cape Henlopen, Delaware
27/0100	Hurricane warning replaced by Tropical Storm Warning	south of Murrels Inlet to Cape Romain
27/0900	Hurricane Warning replaced by Tropical Storm Warnings	south of Little River Inlet, NC to Murrels Inlet, SC
	Tropical Storm Watch issued	from north of Cape Henlopen to Sandy Hook, NJ including Delaware Bay
	Tropical Storm Warning discontinued	from south of Murrels Inlet
27/1500	Tropical Storm Warning issued	from new River Inlet, NC to Cape Henlopen, DE including Palmico and Albemarle Sounds and Chesapeake Bay southward from Smith Point
	Tropical Storm Watch issued	Chesapeake bay from Smith Point to Drum Point and for the Potomac River from Cobb Point to Smith Point
27/2100	Tropical Storm Warning extended northward	from New River Inlet NC to Watch Hill, RI including Palmico and Albemarle Sounds, Chesapeake Bay southward from Smith Point and Delaware Bay
	Tropical Storm Watch issued	from east of Watch Hill, RI to Plymouth, MA
28/0300	Tropical Storm Warning discontinued	south of Cape Lookout, NC
28/0900	Tropical Storm Warning issued	from Watch Hill to Plymouth
	Tropical Storm Warning discontinued	south of Ocracoke, NC and for the Chesapeake Bay and Potomac River north of Smith Point
28/1500	Tropical Storm Warning discontinued	south of NC/VA border including Pamlico and Albemarle Sounds and for Chesapeake and

		Delaware Bays
28/2100	Tropical Storm Warning discontinued	south of Watch Hill including Delaware Bay and Long Island Sound
29/0300	Tropical Storm Warning discontinued	remainder of the U.S. East coast

·opical Cyclone watches and warnings are issued by respectively countries in coordination with the National ·ricane Center.

Table 4. Preliminary forecast evaluation of Hurricane Bonnie. Heterogeneous sample. (Errors in nautical miles for tropical storm and hurricane stages with number of forecasts in parenthesis)

Forecast Technique	Period (hours)				
	12	24	36	48	72
CLIP	60 (41)	127 (40)	196 (38)	258 (36)	318 (32)
GFDI	47 (39)	86 (38)	136 (37)	203 (36)	397 (32)
GFDL*	43 (34)	79 (34)	116 (33)	180 (33)	348 (31)
LBAR	44 (41)	89 (40)	137 (38)	213 (36)	393 (32)
AVNI	46 (41)	89 (40)	140 (37)	214 (37)	468 (30)
BAMD	40 (41)	66 (40)	87 (38)	137 (36)	183 (32)
BAMM	40 (41)	81 (40)	112 (38)	142 (36)	242 (32)
BAMS	69 (41)	124 (40)	162 (38)	194 (36)	327 (32)
NGPI	42 (34)	78 (33)	117 (31)	157 (29)	226 (25)
UKMI	46 (40)	78 (39)	117 (31)	143 (35)	214 (31)
NHC OFFICIAL	45 (41)	86 (39)	129 (37)	172 (36)	232 (32)
NHC OFFICIAL (1988-1997)	47 (1838)	88 (1633)	127 (1449)	165 (1284)	248 (1006)

Preliminary Report
Hurricane Dennis
24 August - 7 September 1999

Jack Beven
National Hurricane Center
11 January 2000

Text-only version
(printer friendly)

Dennis was a larger-than-average western Atlantic hurricane that was erratic in both track and intensity. Although it never made landfall as a hurricane, it affected the North Carolina coast with hurricane force winds, heavy rains, prolonged high surf, and beach erosion. Dennis also produced tropical storm force winds over portions of the Bahamas.

a. Synoptic History

The origin of Dennis can be traced to a tropical wave that moved off the coast of Africa on 17 August. The system moved westward with little significant weather until 21 August, when associated shower activity increased a few hundred miles northeast of the Leeward Islands. A low- level circulation developed over the next two days as convective organization increased. An investigative flight by the Air Force Reserve Hurricane Hunters failed to find a surface circulation on the 23rd. However, the aircraft data indicated a circulation was present at 850 mb. Later surface observations showed a closed circulation, and it is estimated that Tropical Depression Five formed at 0000 UTC 24 August about 190 n mi east of Turks Island (Table 1 and Figure 1). Reconnaissance data and ship reports indicated further intensification, and the depression became Tropical Storm Dennis at 1200 UTC the same day.

The initial structure was unusual. Dennis was at the east-southeast end of an elongated trough that extended to southern Florida. This and upper-level westerly shear caused an asymmetric pattern of convection and tropical storm force winds, with both confined to the eastern semicircle on 24-25 August. Despite the shear, the cyclone intensified unsteadily and reached hurricane strength early on the 26th.

The unusual structure may have also affected the cyclone's motion. Dennis initially moved at 9 to 12 kt, but slowed to an erratic 3 kt on 25 August as steering currents weakened due to a mid-latitude trough passing to the north. At one time that day, the center appeared to re-form eastward along the trough axis. Once Dennis reached hurricane strength, it began a more steady northwestward motion near or over the eastern Bahamas. This motion continued into the 28th.

Westerly shear persisted, preventing significant strengthening until late on 27 August. After the shear decreased, Dennis reached a peak intensity of 90 kt on the 28th and maintained that intensity until early on the 30th. Even at peak intensity, Dennis never consolidated into a classic tightly-wound hurricane. The eye was 30 to 40 miles wide, and on several center fixes the Hurricane Hunters did not report an eye. The radius of maximum winds was as large as 70 to 85 nm on the 29th and 30th.

A second mid-latitude trough caused Dennis to turn gradually northward on 28-29 August, which was followed by acceleration to the east-northeast on 30th and 31th. This turn kept the center about 60 miles south of the North Carolina coast. The east-northeast motion continued until the trough passed Dennis on the 31st. At that time, steering current collapsed and the cyclone slowed to an erratic drift about 110 n mi east of Cape Hatteras, NC. The erratic motion would last into 2 September.

During this time, Dennis became involved with the cold front associated with the mid-latitude trough. A combination of vertical shear and cool dry air entraining into the circulation decreased the convection and weakened the cyclone. Dennis weakened to a tropical storm on 1 September, and on the 1st and 2nd may have been as much a subtropical or extratropical cyclone as a tropical cyclone. Despite the lack of convection, surface observations indicate maximum sustained winds were near 45 kt during 2 September. Some of these winds were due to the combination of Dennis and a strong surface ridge north of the front, which caused 34 kt or greater winds as far north as the New Jersey coast.

A large westerly ridge over the eastern United States forced Dennis southward late on 2 September. This motion toward warmer water probably aided a deep convective burst on the next day. Later that day, Dennis turned northwest toward the North Carolina coast as the ridge moved east into the Atlantic. This motion continued on the 4th along with re-intensification. Dennis was just below hurricane strength when it made landfall over the Cape Lookout National Seashore just east of Harkers Island, NC at 2100 UTC that day. Dennis continued inland and weakened to a depression on the 5th over central North Carolina. Even in dissipation, Dennis continued to move erratically. Figure 1 shows that the cyclone followed a zig-zag course northward for the rest of its life. Dennis became extratropical on the 7th and was absorbed into a larger low on the 9th.

b. Meteorological Statistics

Table 1 shows the best track positions and intensities for Dennis, with the track plotted in Figure 1. Figure 2 and Figure 3 depict the curves of minimum central sea-level pressure and maximum sustained one-minute average "surface" (10 m above ground level) winds, respectively, as a function of time. These figures also contain the data on which the curves are based: aircraft reconnaissance and dropsonde data from the Air Force Reserve Hurricane Hunter and NOAA, satellite-based Dvorak technique intensity estimates from the Tropical Analysis and Forecast Branch (TAFB), the Synoptic Analysis Branch (SAB) of the National Environmental Satellite Data and Information Service (NESDIS), and the Air Force Weather Agency, and estimates from synoptic data.

1. Wind and Pressure Data

The Hurricane Hunters flew 24 missions into Dennis and made 81 center fixes, and NOAA research aircraft provided three additional fixes during various research missions. The maximum reported wind was 110 kt (at 700 mb) at 2002 UTC 28 August. While taking 90% of this wind would suggest a maximum sustained surface wind of 99 kt, dropsonde observations at that time do not support that high of a surface wind. The minimum observed central pressure observed from dropsondes was 962 mb at 0350 and 0543 UTC on 30 August. A 959 mb pressure was estimated from 700 mb data at 1017 UTC on the 30th, (Figure 2), but is believed to be too low. The Hurricane Hunters also measured 71 kt winds (at 850 mb) and a 984 mb pressure just before Dennis made landfall on 4 September. These data indicate Dennis was a 60 kt tropical storm at landfall.

Dennis's path brought it near the eastern Bahamas on 27-28 August. The only official report of tropical storm force winds in the Bahamas was from the Coastal Marine Automated Network (C-MAN) station at Settlement Point, Grand Bahama, which reported 34 kt sustained winds with gusts to 46 kt at 0030 UTC 29 August. (This and other available surface observations are summarized in Table 2.) However, reports relayed to the NHC through amateur radio operators indicated sustained winds of up to 60 to 65 mph with gusts of 70 to 75 mph in the Abaco island group. Reported pressures were as low as 976 mb as the western part of the eye passed over the Abacos around 0700 to 1000 UTC on the 28th. While these observations are significant, their reliability is uncertain. Therefore, they are not included in Table 2.

Dennis tracked parallel to the Florida and Georgia coasts, with tropical storm force winds remaining mostly offshore. The only reported tropical storm force wind was a 41 kt gust at the St. Augustine, FL C-MAN station. The core of Dennis passed just east of NOAA buoy 41010 on 29 August, which reported 57 kt sustained winds with gusts to 72 kt at 0500 UTC and a minimum pressure of 980.2 mb at 0750 UTC.

Dennis's first pass near the coast of the Carolinas on 30 August caused sustained tropical storm force winds with gusts to hurricane force in coastal North Carolina and gusts to tropical storm force in coastal South Carolina from Charleston northward. The maximum reported sustained winds were 53 kt with gusts to 77 kt at Oregon Inlet at 2030 UTC. It is not clear whether sustained hurricane force winds affected the coast. There are no observations of such winds, and analyses from the Hurricane Research Division suggests they stayed offshore. However, gusts to 96 kt at Wrightsville Beach and 85 kt at Hatteras Village (Table 2) suggest that sustained hurricane force winds may have occurred along the coasts of New Hanover and Dare counties. Sustained hurricane force winds of 81 kt with gusts to 97 kt were measured at the Frying Pan Shoals C-MAN station (145 ft elevation) at 0945 UTC 30 August, with a minimum pressure of 977.2 mb at 0900 UTC.

The landfall of Dennis on 4 September produced tropical storm force winds over portions of eastern North Carolina and coastal southeastern Virginia. Langley Air Force Base VA, reported 45 kt sustained winds with gusts to 66 kt at 2330 UTC, while Cherry Point Marine Corp Air Station NC, reported 41 kt sustained winds with gusts to 53 kt at 2005 UTC.

The large circulation of Dennis also affected shipping over a portion of the western Atlantic. Table 2a shows the available ship observations of tropical storm force or greater winds. The maximum ship-observed winds were 65 kt from the **Zim U.S.A.** at 0900 UTC 30 August, while the lowest observed pressure was 987.3 mb from the **Hoegh Dene** at 1800 UTC 4 September. Observations from the **Sealand Crusader** on 24 August were important in determining that the pre-Dennis wave had developed into a depression.

2. Storm Surge Data

Few detailed observations of storm surge are available from areas affected by Dennis (Table 2). Storm tides of 3 to 5 ft above normal were reported along much of the North Carolina coast on both 30 August and 4 September. Areas along the Neuse River reported tides of 8 to 10 ft above normal tide level on 30 August, while areas along the Pamlico River reported similar values on 4 September. Portions of the South Carolina and southeastern Virginia coast experienced 2 to 4 ft above normal tides during Dennis, while amateur radio reports from the Bahamas indicate tides 1 to 3 ft above normal as the eye passed over the Abacos.

Since Dennis meandered off the North Carolina coast for several days, the above normal tides were unusually prolonged. This led to extensive beach erosion along portions of the North Carolina and southeastern Virginia coasts.

3. Rainfall data

Dennis affected the mid-Atlantic states twice within a week, and other weather systems affected the region during the same period. This makes determination of storm total rainfall in that area difficult. Table 2 shows the storm total rainfalls for Dennis, including the best estimates in North Carolina and Virginia. The maximum reported total was 19.13 inches at Ocracoke NC, with 6 to 10 inches reported elsewhere over portions of eastern North Carolina. Rainfalls of 3 to 6 inches occurred elsewhere over eastern North Carolina, extreme eastern South Carolina, and over portions of southeastern Virginia. Rainfalls were generally 1 to 3 inches elsewhere over eastern South Carolina and less than an inch in Florida and Georgia.

Dennis and the other weather systems contributed to a wet period over portions of the mid-Atlantic states. Table 2b shows 11-day rainfall totals of 6 inches or more ending at 1200 UTC 8 September. The heaviest rainfalls were observed over eastern North Carolina and central Virginia. While this rainfall broke a prolonged dry spell in the area, it also set the stage for the severe flooding caused by Hurricane Floyd two weeks later.

Official rainfall data from the Bahamas indicates a maximum total of 4.00 inches at Cat Island. Heavier amounts likely occurred on Eleuthera and in the Abaco group near the eye of Dennis.

4. Tornadoes

One tornado was reported with Dennis on 4 September. This F2 tornado in

Hampton VA caused an estimated $7 million damage and 15 injuries, 6 of them serious.

c. Casualty and Damage Statistics

Four deaths reported in Florida were related to high surf spawned by the hurricane. No deaths are known due to winds, rains, storm tides or tornadoes associated with Dennis.

In the United States, the Property Claims Services Division of the Insurance Services Office reports insured losses due to Dennis totaled $60 million in North Carolina and Virginia. To determine the total property damage, a two to one ratio is applied to the insured property damage based on comparisons done in historical hurricanes. Press reports indicate that agricultural losses in North Carolina and Virginia were $37 million. Combining these reports gives a total estimated damage from Dennis of $157 million.

There are no damage reports available from the Bahamas as of this time.

d. Forecast and warning critique

Table 3 shows the track forecast errors during Dennis for the official NHC track forecast and a selection of objective guidance models. The official forecasts were generally quite good with errors of about 60% to 70% of the long term average. The official forecasts also were better than the objective guidance with two exceptions: The United Kingdom Meteorological Office global model (UKM) was slightly better than the official forecast at all time periods, and the barotropic model LBAR was slightly better at 12 and 24 hours. It should the noted that the UKMI, which is the interpolated UKM track forecast available to hurricane forecasters in real time, was slightly worse than the official forecast at all time periods. There were two periods with worse than average official track forecasts. The first was on 24 August, as the poorly-organized Dennis consistently moved slower than forecast. The second on was 28 August, when the motion parallel to the coast on 30-31 August was poorly forecast.

While intensity forecast errors were also better than the long term average, there was a significant positive bias which is counter to the 10-year average. This occurred due to forecasts on 28-30 August which predicted Dennis to remain a hurricane when it actually weakened to a tropical storm. Three consecutive forecasts during this time overforecasted the 72 hour intensity by 50 kt.

Table 4 shows the watches and warnings that were issued for Dennis. Due to the somewhat erratic motion near the Bahamas, hurricane warnings were issued for Eleuthera and the Abacos 40 hours before the eye passed over the Abacos. While tropical-storm force winds did not occur over land south of Charleston, SC, they were present over the Florida, Georgia, and South Carolina coastal waters. Hurricane warnings for the North Carolina coast on 29 August had less than the normally-desired 24 hour lead time. However, these were issued in anticipation that Dennis' large size and track just offshore would cause hurricane conditions along the coast and not in anticipation of a landfall. Hurricane warnings were also issued for the North Carolina coast on 4 September in anticipation of Dennis regaining hurricane strength before landfall. These proved to be unnecessary.

Acknowledgments:

Much of the data in this report was provided by the local National Weather Service forecast offices in Miami, Melbourne, Jacksonville, Charleston, Wilmington, Morehead City, and Wakefield. Buoy and C-MAN station data was provided by the National Data Buoy Center. James Franklin created the wind and pressure plots.

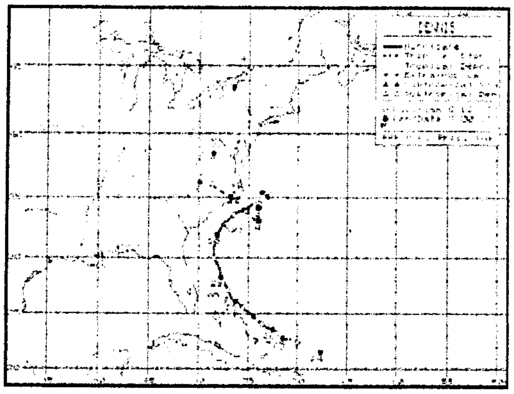

Figure 1. Best track for Hurricane Dennis, 24 August - 7 September 1999.

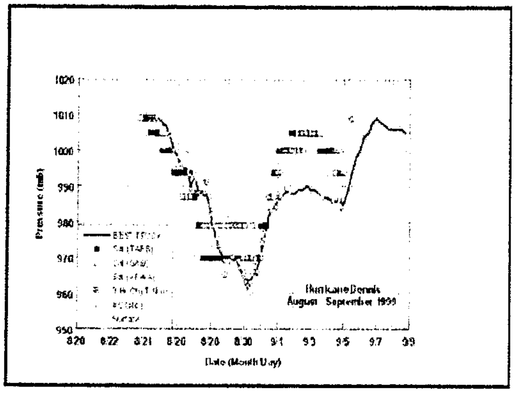

Figure 2. Best track minimum central pressure curve for Hurricane Dennis, 24 August - 7 September 1999.

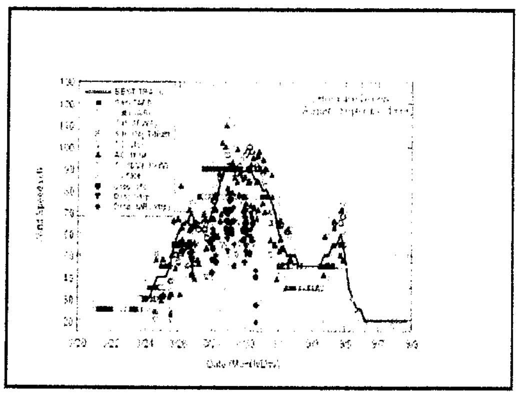

Figure 3. Best track maximum sustained 1-minute 10 meter wind speed curve for Hurricane Dennis, 24 August - 7 September, 1999.

Table 1. Best track, Hurricane Dennis, 24 August - 7 September 1999

Date/Time (UTC)	Position		Pressure (mb)	Wind Speed (kt)	Stage
	Lat. (°N)	Lon. (°W)			
24/0000	21.5	67.7	1009	30	tropical depression
24/0600	22.0	68.9	1009	30	"
24/1200	22.4	70.0	1009	35	tropical storm
24/1800	22.7	70.9	1009	40	"
25/0000	22.8	71.5	1008	40	"
25/0600	23.0	71.9	1007	40	"
25/1200	23.2	72.1	1004	45	"
25/1800	23.4	72.3	1000	55	"
26/0000	23.6	72.5	998	60	"

26/0600	23.8	73.1	995	65	hurricane
26/1200	24.1	73.6	995	65	"
26/1800	24.4	74.0	990	70	"
27/0000	24.8	74.4	993	65	"
27/0600	25.2	75.0	988	65	"
27/1200	25.6	75.5	988	65	"
27/1800	25.9	75.9	987	65	"
28/0000	26.1	76.2	982	70	"
28/0600	26.5	76.7	976	75	"
28/1200	27.1	77.0	973	85	"
28/1800	27.7	77.3	969	90	"
29/0000	28.3	77.7	969	90	"
29/0600	29.0	77.9	970	90	"
29/1200	29.9	78.4	971	90	"
29/1800	30.8	78.4	967	90	"
30/0000	31.9	78.1	964	90	"
30/0600	32.8	77.6	962	90	"
30/1200	33.6	76.5	965	85	"
30/1800	34.3	74.8	966	85	"
31/0000	34.9	73.6	971	80	"
31/0600	35.1	72.9	977	80	"
31/1200	35.2	72.8	983	75	"
31/1800	35.1	73.3	984	70	"
01/0000	35.2	73.6	986	60	tropical storm
01/0600	35.0	73.4	987	55	"
01/1200	35.4	73.5	989	50	"
01/1800	35.5	73.8	988	50	"
02/0000	35.4	73.7	988	50	"
02/0600	35.2	73.6	989	45	"
02/1200	35.1	73.7	989	45	"
02/1800	34.8	73.9	990	45	"
03/0000	34.2	74.0	989	45	"
03/0600	33.6	74.1	989	45	"
03/1200	33.2	73.9	988	45	"
03/1800	33.0	73.8	987	50	"
04/0000	33.1	74.0	987	50	"
04/0600	33.3	74.5	986	55	"
04/1200	33.9	75.3	986	55	"
04/1800	34.5	76.0	986	60	"
05/0000	35.0	76.8	985	50	"
05/0600	35.5	77.7	989	35	"
05/1200	36.1	78.8	994	30	tropical depression
05/1800	36.2	79.4	998	25	"
06/0000	36.2	79.9	1000	25	"
06/0600	36.4	80.1	1004	20	"
06/1200	37.0	79.9	1005	20	"
06/1800	37.7	79.5	1008	20	"
07/0000	38.5	78.5	1009	20	"
07/0600	40.8	77.0	1008	20	"
07/1200	42.7	77.7	1007	20	"
07/1800	43.5	77.7	1006	20	extratropical
08/0000	43.5	76.5	1006	20	"
08/0600	44.0	75.8	1006	20	"
08/1200	44.9	74.8	1006	20	"
08/1800	45.5	75.6	1005	20	"
09/0000					lost identity

30 /0600	32.8	77.6	962	90	minimum pressure
Landfalls:					
28/0700	26.6	76.8	976	75	Abaco Islands, Bahamas
04/2100	34.8	76.5	984	60	Cape Lookout National Seashore, NC

Table 2. Hurricane Dennis selected surface observations, 24 August - 7 September 1999. (Incomplete pending further data from NDBC)

	Minimum sea-level pressure		Maximum surface wind speed (kt)					
Location	**Pressure (mb)**	**Date/time (UTC)**	**Sustained wind (kts) [a]**	**Peak gust (kts)**	**Date/time[b] (UTC)**	**Storm surge[c] (ft)**	**Storm tide[d] (ft)**	**Rain (storm total) (in)**
Bahamas								
Cat Island								4.00
North Carolina								
Alligator Bridge[#]			48	56	30/1100			
Atlantic (Texas Tech tower, 30 ft)	992.6	30/1351	48	75	30/1532			
Beaufort	984.8	04/2049	33	45	04/1823			
Beaufort (Texas Tech tower, 33 ft)	992.8	30/1302	52	75	30/1103			
Blockade Runner				72				
Brunswick Cnty Airport				61	30/0810			
Brunswick Power Plant			50[g]		30/0456			
Calabash				35				1.57
Carolina Beach				66	30/0710			
Castle Hayne (Oxychem)				54	30/1100			
Castle Hayne (SW)			35	67	30/0900			
Cherry Point MCAS	986.5	04/2355	41	53	04/2005			9.24
Delco			28	57	30/1200			
East Waccamaw				34	30/1100			0.98
Elizabeth City	1003.8	04/2313	34	45	30/1654			7.01
Elizabethtown				37				
Flemington			39	68	30/0900			
Greenville				43	05/0140			
Harkers Island Bridge				76	30/1230			
Hatteras Inlet			50[$]	64	30/1930			
Hatteras Village				85	30/1515			
Jacksonville	994.2	05/0235		41	30/0835			
Kingston				37	04/2250			
Kure Beach				58	30/0740			
Kure Beach (Federal Point)				71	30/0530			
Manteo				52	30/1635			
New Bern	986.8	05/0000	35	46	30/1056			3.35
New River	993.9	04/2126	33	50	30/0956			5.75

Florida Public Service Commission
Docket No. 070299-EI
GULF POWER COMPANY
Witness: E. J. Battaglia
Exhibit No. ____ (EJB-2)
Schedule 6
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Newport	985.1	04/2115		54	30/1204			9.89
North Topsail Beach			44[$]	65	30/1240			
Oak Island			46	62	30/0800			
Ocean Isle				49	30/0559			
Ocean Isle (Tubbs Inlet)				46	30/0753			
Ocracoke Island[#]	995.1	31/0740	35[$]	58	31/0220			19.13
Oregon Inlet			53[$]	77	30/2030			
Oriental							6-8	
St. James								6.00
Shallotte				60	30/0700			
Shallotte Inlet				60	30/0730			
Southport (Elementary)				49				9.01
Southport (Marina)								13.50
Southport (Pilot Boat Dispatch)				60	30/0743			
Washington				41	30/1520			
Whiteville				37				1.97
Wilmington Airport	996.1	0953	42	53	30/0607			4.73
Wilmington (Battleship North Carolina)				66	30/0530			6.70
Wilmington (College RD/Oleander DR)				46				8.75
Wilmington (Corning)				60	30/1200			
Wilmington (Eastwood RD/Military Cutoff)				44	30/0650			6.60
Wilmington (Masonboro Loop)				37				
Wilmington (New Hanover EOC)			51	76	30/0800			
Wilmington (WECT-TV)				46				5.07
Wrightsville Beach				96	30/0444			
Wrightsville Beach Fire Dept.				73	30/0630			
South Carolina								
Charleston Harbor							2.0	
Charleston WFO			29	40	29/2050			1.22
Murrells Inlet								2.88
Myrtle Beach (Pavilion)				45	30/0600			
N. Myrtle Beach			29	42	30/0732			1.65
Virginia								
John Kerr Dam								3.38
Norfolk Airport	1006.1	05/0551	37	46	30/1651			3.30
Langely AFB	1007.1		45	66	04/2332			
Newport News	1006.5		28	39	04/2332			3.32
Norfolk NAS	1006.5							2.85

Oceana NAS	1006.5							2.90
Portsmouth								5.75
Richmond	1006.5	05/0754						2.18
Roanoke Rapids			27	35	30/1214			
Sewells Point							3.0	
Wakefield								4.59
Wallops Island			33	40	30/1717			
NOAA Buoys and C-MAN Stations								
Buoy 41001	976.0	31/0400	48[$]	63	30/2300			
Buoy 41002	997.6	30/1100	43[$]	59				
Buoy 41004	990.5	30/0300	54[$]	72	30/0330			
Buoy 41008	1003.9	29/2000	31	43	29/1700			
Buoy 41009[#]	1001.3	29/0900	29	37	29/0700			
Buoy 41010	980.2	29/0750	57	72	29/0500			
Buoy 44014	1002.3	30/2000	43	53	30/2100			
Drifting Buoy 41650[#]	1009.8	27/0000	45		27/1200			
Drifting Buoy 41651[#]	1010.8	25/2100	42		25/2100			
Cape Lookout NC (CKLN7)	986.5	04/2000	60	79	30/1400			
Chesapeake Bay VA (CHLV2)	1006.2	05/0600	49[$]	56	30/2100			
Duck NC (DUCN7)	1005.6	04/2300	56	65	30/2000			
Folly Beach SC (FBIS1)	1001.6	30/0100	24	35	30/0000			
Frying Pan Shoals NC (FPSN7)	977.2	30/0900	81[$]	97	30/0945			
Settlement Point, BI (SPGF1)	1002.6	28/2200	34[$]	46	29/0030			
St. Augustine FL (SAUF1)	1004.9	29/1100	27	41	29/1355			

[a]Standard NWS ASOS and C-MAN averaging period is 2 minutes; buoys are 8 minutes.
[b]Date/time is for sustained wind when both sustained and gust are listed.
[c]Storm surge is water height above normal astronomical tide level.
[d]Storm tide is water height above NGVD.
[e]Estimated.
[$]10 min average.
[g]100 ft tower, 15 min average.
[#]Incomplete record.

Table 2a. Ship observations of tropical storm or greater winds associated with Hurricane Dennis, 24 August - 7 September 1999.

Ship	Date/Time (UTC)	Lat. (°N)	Lon. (°W)	Wind dir/speed (deg/kt)	Pressure (mb)
Sealand Crusader	24/0600	21.0	67.0	130/35	1011.5
Iver Express	24/1800	23.2	74.6	010/39	1012.0
Jo Sypress	26/1500	25.9	73.0	120/39	1012.5
Nomzi	27/0000	25.9	74.3	090/44	1010.0
Nomzi	27/0300	25.9	74.0	090/45	1010.0
Nomzi	27/0600	26.0	73.7	070/40	1011.0
Star Hidra	28/2100	30.1	77.5	050/40	1005.0
Morelos	28/2100	26.2	74.4	170/34	1007.0
Torm Freya	29/0000	30.2	75.5	100/35	1005.0

Nedlloyd Holland	29/0000	27.8	79.2	340/42	1002.0
Star Hidra	29/0000	30.0	77.0	050/41	1004.0
Nedlloyd Holland	29/0300	28.7	79.9	340/39	1002.2
Star Hidra	29/0300	29.5	76.4	090/55	1001.0
Torm Freya	29/0600	29.5	74.8	150/48	1005.0
Star Hidra	29/0600	29.8	76.5	120/56	999.3
Star Hidra	29/0900	29.7	76.4	150/56	999.5
Star Hidra	29/1200	29.6	76.2	160/55	1000.5
Star Hidra	29/1500	29.3	76.1	180/46	1003.0
Torm Freya	29/1800	28.3	74.9	190/46	1007.0
Zim U.S.A.	29/2100	32.0	75.0	140/38	1006.0
Star Hidra	29/2100	28.8	77.1	210/37	1005.5
Zim U.S.A.	30/0000	32.0	75.1	160/40	1004.0
Zim U.S.A.	30/0300	32.0	75.3	160/50	1002.0
Zim U.S.A.	30/0600	31.8	75.5	180/65	999.0
OOCL Fair	30/0600	33.4	74.3	150/40	1005.0
Zim U.S.A.	30/0900	32.3	75.0	180/65	1000.0
OOCL Fair	30/0900	32.7	74.3	180/50	1002.0
Zim U.S.A.	30/1200	31.4	75.7	250/50	1002.5
SHIP	30/1200	36.9	75.0	040/40	1014.5
Zim U.S.A.	30/1500	31.5	76.3	270/50	1006.0
OOCL Fair	30/1500	32.1	74.6	210/50	1002.0
Inspiration	30/1800	35.8	71.9	080/50	1006.0
OOCL Fair	30/1800	32.0	75.0	260/55	1006.0
Inspiration	30/2100	35.6	72.6	090/55	1002.5
Barbet Arrow	31/1200	32.5	71.5	240/40	1009.2
Stonewall Jackson	31/1200	33.5	71.7	230/55	1003.5
SealandPerformance	31/1200	35.1	70.1	160/45	1005.0
Barbet Arrow	31/1800	32.4	72.3	250/40	1015.0
Edyth L.	31/1800	34.8	75.1	310/55	1005.7
Stonewall Jackson	31/1800	33.4	72.7	250/45	1007.0
Sealand Performance	31/1800	33.7	69.8	230/40	1009.5
Stonewall Jackson	02/0000	33.5	75.1	300/36	1010.0
Trojan Star	02/0000	36.8	70.7	110/38	1010.1
V2PE1	02/0600	33.9	72.2	220/40	1008.0
Shanghai Senator	02/0900	37.6	75.1	040/35	1011.0
V2PE1	02/1200	35.0	72.1	200/43	1005.2
OOCL Friendship	02/1800	34.1	74.7	300/45	999.2
V2PE1	02/1800	35.6	72.9	140/42	1004.5
OOCL Friendship	02/2100	34.1	73.5	200/45	993.6
V2PE1	03/0600	36.3	75.3	040/40	1010.5
Chemical Pioneer	03/1500	34.3	76.3	320/40	1004.7
Chemical Pioneer	03/1800	34.7	75.8	340/35	1004.7
Hoegh Dene	04/0600	33.1	77.3	100/39	1005.3
Hoegh Dene	04/1200	33.8	76.4	360/37	1000.0
Hoegh Dene	04/1500	34.1	76.0	110/39	992.5
Hoegh Dene	04/1800	34.4	75.6	150/40	987.3
Mette Maersk	04/1800	35.4	74.4	110/45	1002.9
Mette Maersk	04/2100	35.8	73.6	120/37	N/A
Hoegh Dene	05/0000	35.5	75.0	140/35	1003.8

Table 2b. Eleven day rainfall totals ending at 1200 UTC 8 September 1999. Data courtesy of the National Climatic Data Center

Station	Rainfall (in)	Station	Rainfall (in)
North Carolina			

Aurora	10.68	Greenville	7.66
Jacksonville	10.54	Edenton	7.33
Cherry Point	10.18	Wilsonville	7.11
Hatteras	9.30	Enfield	7.01
Apex	8.87	Kinston	6.80
Raleigh/Durham	8.46	Rougemount	6.69
Elizabeth City	8.17	Rocky Mount	6.53
Goldsboro (GSB)	8.04	Butner	6.50
Goldsboro	7.76	Arcola	6.34
Neuse	7.72	New Bern	6.09
Wilson	7.69	Oxford	6.07
Pennsylvania			
Lochiel	7.23	Elimsport	6.90
Williamsport	7.00	Loyalsockville	6.90
South Carolina			
Myrtle Beach	6.02		
Virginia			
Allisonia	13.82	Fincastle (DAEV2)	7.03
Buchanan	12.91	Mauretown	7.00
Front Royal (HOGV2)	12.86	Lovingston (LOVV2)	6.87
Roanoke (WITV2)	10.33	Front Royal (LIMV2)	6.76
Montebello	9.40	Lovingston (BRNV2)	6.68
Copper Hill (COPV2)	8.31	Strasburg	6.57
Fincastle (TIKV2)	7.63	Waynesboro	6.52
Copper Hill (COHV2)	7.62	Springcreek	6.50
Alberta	7.49	Roanoke (FOTV2)	6.44
Winterpock	7.33	South Boston	6.41
Algoma	7.11	Glasgow	6.28
Mathews	7.10	Pedlar Mills	6.20
Luray	7.09		

Table 3. Preliminary track forecast evaluation for Hurricane Dennis - heterogeneous sample. Errors in nautical miles for tropical storm and hurricane stages with number of forecasts in parentheses. Numbers in boldface represent forecast which were better than the official forecast.

Forecast Technique	Period (hours)				
	12	24	36	48	72
CLIP	44 (46)	92 (44)	150 (42)	209 (40)	360 (36)
GFDI	40 (38)	75 (36)	110 (34)	148 (32)	213 (29)
GFDL*	40 (36)	69 (34)	100 (32)	136 (30)	209 (27)
LBAR	**31** (46)	**61** (44)	99 (42)	137 (40)	217 (36)
AVNI	53 (42)	100 (40)	139 (38)	175 (35)	220 (26)
AVNO*	46 (40)	93 (37)	134 (35)	163 (32)	213 (22)
BAMD	35 (45)	65 (44)	102 (41)	144 (39)	212 (35)
BAMM	43 (46)	84 (44)	128 (42)	168 (40)	260 (36)
BAMS	56 (46)	111 (44)	169 (42)	230 (40)	343 (36)
NGPI	48 (44)	76 (42)	108 (40)	133 (38)	184 (30)
NGPS*	46 (23)	77 (22)	100 (21)	133 (20)	173 (16)
UKMI	41 (41)	68 (39)	96 (38)	118 (37)	161 (33)
UKM*	**33** (23)	**61** (22)	**82** (21)	**106** (20)	**147** (18)
A90E	39 (45)	73 (43)	100 (41)	138 (39)	228 (35)
A98E	38 (40)	73 (38)	110 (36)	151 (34)	240 (30)
A9UK	37 (22)	73 (21)	108 (20)	147 (19)	274 (17)
NHC Official	34 (46)	63 (44)	90 (42)	112 (40)	160 (36)

NHC Official 10-Year Average (1989-1998)	48 (2005)	89 (1790)	128 (1595)	164 (1410)	242 (1107)

*Output from these models was unavailable at time of forecast issuance.

Table 4. Watch and warning summary, Hurricane Dennis, 24 August- 7 September 1999.

Date/Time (UTC)	Action	Location
24/1500	Tropical Storm Warning issued	Bahamas...Turks and Caicos Islands and SE Bahamas
24/1500	Tropical Storm Watch issued	Central Bahamas.
25/0900	Hurricane Watch and Tropical Storm Warning issued	Central Bahamas.
25/0900	Hurricane Watch issued	Northwest Bahamas.
26/0900	Tropical Storm Warning discontinued	Bahamas...Turks and Caicos Islands and SE Bahamas.
26/1500	Hurricane Warning issued	Central Bahamas. Northwest Bahamas...Eleuthera and the Abacos.
27/0300	Tropical Storm Warning issued	Northwest Bahamas...New Providence, Grand Bahama, and the Berry Islands.
27/0900	Hurricane Warning issued	Northwest Bahamas...remainder.
27/1500	Hurricane Watch issued	Florida....Sebastian Inlet to Fernandina Beach.
27/1500	Hurricane Warning discontinued	Central Bahamas...including Andros and New Providence Islands.
27/2100	Tropical Storm Warning issued	Florida...Sebastian Inlet to Flagler Beach.
28/0900	Hurricane Warning discontinued	Bahamas...Eleuthera and the Berry Islands.
28/2100	Hurricane Warning discontinued	Bahamas...Abacos and Grand Bahama Islands.
29/0300	Hurricane Watch issued	N of Savannah, GA to Surf City, NC.
29/0300	Hurricane Watch discontinued	Florida...Sebastian Inlet to Fernandina Beach.
29/0900	Tropical Storm Warning issued	N of Savannah, GA to Surf City, NC.
29/0900	Hurricane Watch issued	North Carolina...Surf City to Cape Hatteras.
29/1500	Tropical Storm Warning issued	North Carolina...Surf City to Cape Hatteras.
29/1500	Tropical Storm Watch issued	N of Cape Hatteras to Cape Charles Light, VA.
29/2100	Hurricane Watch upgraded to Hurricane Warning	Little River Inlet, SC to Oregon Inlet, NC...including Pamlico Sound.
29/2100	Tropical Storm Warning issued	Oregon Inlet, NC to Chincoteague, VA...including Abermarle Sound and southern Chesapeake Bay south of New Point Comfort.
30/0300	Hurricane Watch and Tropical Storm Warning discontinued	Edisto Beach, SC to Savannah, GA.
30/0900	Hurricane Watch upgraded to Hurricane Warning	Oregon Inlet, NC to North Carolina/Virginia border.
30/0900	Gale Warning issued	Chincoteague, VA to Cape Henlopen, DE.
30/0900	Hurricane Watch and Tropical Storm Warning discontinued	N of Savannah, GA to Little River Inlet, SC.
30/2100	Hurricane Warning discontinued	South of Cape Lookout, NC to Little River Inlet, SC.
31/0300	Hurricane Warning downgraded to Tropical Storm Warning	Cape Lookout, NC to NC/VA border.
31/0900	Gale Warning issued	Cape Henlopen, DE to Great Egg Inlet, NJ.
01/0300	Tropical Storm Warning and a Hurricane Watch issued	Surf City, NC to Chincoteague, VA...including Pamlico and Ablemarle Sounds and southern Chesapeake Bay south of New Point Comfort.
01/1500	Hurricane Watch discontinued	Surf City, NC to Chincoteague, VA...including Pamlico and Ablemarle Sounds and southern Chesapeake Bay south of New Point Comfort.
02/0600	Gale Warning discontinued	Fenwick Island, DE to Cape Henlopen, DE.
02/0600	Gale Warning issued	Chincoteague, VA to Fenwick Island, DE.
02/1500	Tropical Storm Warning discontinued	North of Cape Charles Light, VA to Chincoteague, VA South of Cape Lookout, NC to Surf City, NC.
02/2100	Tropical Storm Warning discontinued	Southern Chesapeake Bay south of New Point Comfort.
03/0300	Tropical Storm Warning discontinued	Cape Charles Light, VA to NC/VA border.
	Tropical Storm Warning	

03/0900	discontinued	Oregon Inlet, NC to NC/VA border.
03/2100	Tropical Storm Watch issued	Oregon Inlet, NC to NC/VA border...including Ablemarle Sound. Cape Lookout, NC to Surf City, NC.
04/0900	Tropical Storm Warning issued	N of Oregon Inlet, NC to the NC/VA border...including Ablemarle Sound. S of Cape Lookout, NC to Surf City, NC.
04/1500	Tropical Storm Warning upgraded to Hurricane Warning	NC/VA border to Surf City, NC...including Pamlico and Ablemarle Sounds.
04/1500	Tropical Storm Warning issued	N of NC/VA border to Chincoteague, VA...including Chesapeake Bay south of Smith Point.
04/2100	Tropical Storm Warning issued	Entire Chesapeake Bay...including the Tidal Potomac.
04/2100	Gale Warning issued	N of Chincoteague, VA to Great Egg Inlet, NJ.
05/0100	Hurricane Warning downgraded to Tropical Storm Warning	NC/VA border to Surf City, NC...including Pamlico and Ablemarle Sounds.
05/0900	Tropical Storm Warning discontinued	NC/VA border to Surf City, NC...including Pamlico and Ablemarle Sounds.

2, 2000

Florida Public Service Commission
Docket No. 070299-EI
GULF POWER COMPANY
Witness: E. J. Battaglia
Exhibit No. ____ (EJB-2)
Schedule 7

Preliminary Report
Hurricane Floyd
7 - 17 September, 1999

Text-only version
(printer friendly)

Richard J. Pasch, Todd B. Kimberlain and Stacy R. Stewart
National Hurricane Center
18 November 1999

Floyd was a large and intense Cape Verde hurricane that pounded the central and northern Bahama islands, seriously threatened Florida, struck the coast of North Carolina and moved up the United States east coast into New England. It neared the threshold of category five intensity on the Saffir/Simpson Hurricane Scale as it approached the Bahamas, and produced a flood disaster of immense proportions in the eastern United States, particularly in North Carolina.

a. Synoptic History

Floyd can be traced back to a tropical wave that emerged from western Africa on 2 September. This system was not particularly impressive-looking, in terms of the organization of the convection shown on satellite images, but there was evidence of curvature in the cloud lines. Overall the system was broad and disorganized, yet easily recognizable as a synoptic-scale entity.

The wave proceeded westward across the eastern tropical Atlantic at about the normal speed of propagation, 6 degrees of longitude per day, with little apparent change, for several days. A center of circulation was estimated late on 5 September near 15N 32.5W but the cloud pattern lacked sufficient deep convection for a Dvorak classification. On 6 September, there was enough of a curved band of deep convection present so that the system was classified as a T1.0 on the Dvorak scale around 1200 UTC. A favorable upper-level outflow pattern existed over the area, and the cloud pattern became more consolidated and better organized on the 7th. Tropical Depression Eight formed about 1000 miles east of the Lesser Antilles by 1800 UTC that day.

A deep-layer ridge prevailed to the north of the cyclone and the associated steering current moved the system west-northwestward at 12-15 knots for a couple of days. When it reached a position about 750 n mi east of the Leeward Islands, the cloud pattern became sufficiently well organized for the system to become Tropical Storm Floyd around 0600 UTC 8 September. Even though large-scale conditions appeared conducive for strengthening, there was a lack of a well-defined inner core. This was evidenced by visible, infrared, and microwave imagery that showed no tightly curved banding features or a concentration of deep convection close to the center, a condition that probably prevented rapid intensification during the early stages of the tropical cyclone. Floyd slowly strengthened and became a hurricane by 1200 UTC 10 September while centered about 200 n mi east-northeast of the northern Leeward Islands.

As Floyd was nearing hurricane status, a mid-tropospheric trough in the vicinity of 60-65W longitude caused a slowing of the forward speed, and then a turn toward the northwest. The northwestward motion continued until the 11th, keeping the hurricane well to the northeast of the islands of the northeastern Caribbean. On the 11th, Floyd neared the southwest portion of the mid-Atlantic upper-tropospheric trough which was situated to the north of Puerto Rico, i.e. close to its climatological position. Historically, hurricanes have had difficulty strengthening in this area. Floyd's upper-level outflow was disrupted over the southern semicircle by the trough and an anticyclone over the eastern Caribbean. Consequently, after strengthening nearly to category three status early on the 11th, the hurricane weakened to 85 knots around 0000 UTC on the 12th. Early on the 12th, rising mid- to upper-tropospheric heights to the north of Floyd forced a turn toward the west. The westward turn also marked the beginning of a major strengthening episode (this phenomenon has also been observed with many past hurricanes, e.g. Andrew of 1992). Maximum sustained winds increased from 95 knots to 135 knots, and the central pressure fell about 40 mb from early on the 12th to early on the 13th. From 0600 to 1800 on the 13th, Floyd was at the top end of category four intensity on the Saffir/Simpson Hurricane Scale.

One potential contributor to the significant strengthening of Floyd was the presence of enhanced upper oceanic heat content along its track. Analyses from the Physical Oceanography Division of NOAA/AOML showed relatively high values of heat content just to the east of the Bahamas a day or two before Floyd passed through the area.

Floyd was aimed at the central Bahamas until late on the 13th, when the heading became west-northwestward. The eye passed just 20 to 30 n mi northeast and north of San Salvador and Cat Islands on the night of the 13th. Floyd's eyewall passed over central and northern Eleuthera on the morning of the 14th, and after turning toward the northwest, Floyd struck Abaco island on the afternoon of the 14th. By the time the hurricane hit Abaco, it had weakened somewhat from its peak, but Floyd was still a borderline category three/four hurricane.

As a mid- to upper-tropospheric trough over the eastern United States eroded the subtropical ridge over the extreme western Atlantic, Floyd continued to turn gradually to the right. The center of the hurricane paralleled the central Florida coast, passing about 95 n mi east of Cape Canaveral around 0900 UTC 15 September. By the afternoon of the 15th, Floyd was abeam of the Florida/Georgia border and headed northward toward the Carolinas.

Although there was a fluctuation in intensity, related to an eyewall replacement event discussed in the next section, overall the intensity of Floyd diminished from the 13th to the 15th. Environmental causes for intensity change are not entirely understood, but two large-scale factors probably contributed to a gradual decline: the entrainment of drier air at low levels from the northwest, and increasing south-southwesterly vertical shear. As Floyd neared the North Carolina coast late on the 15th, its maximum winds decreased below category three status.

After turning toward the north-northeast with forward speed increasing to near 15 knots, Hurricane Floyd made landfall near Cape Fear, North Carolina at 0630 UTC 16 September as a category two hurricane with estimated maximum winds near 90 knots. Floyd was losing its eyewall structure as it made landfall. Continuing to accelerate north-northeastward, Floyd's center passed over extreme eastern North Carolina on the morning of the 16th and over the greater Norfolk, Virginia area around 1500 UTC that day. Floyd then weakened to a tropical storm and moved swiftly along the coasts of the Delmarva peninsula and New Jersey on the afternoon and early evening of the 16th, reaching Long Island by 0000 UTC 17 September. By that time, the storm's forward speed had increased to near 29 knots. The system decelerated as it moved into New England.

By late on the 16th and early on the 17th, Floyd was becoming more involved with a frontal zone that existed along the Atlantic seaboard. The system took the form of a frontal low and thus became extratropical by the time it reached the coast of Maine at 1200 UTC 17 September. The cyclone turned toward the northeast and then east-northeast, moving over the coast of New Brunswick late on the 17th, Prince Edward Island early on the 18th and Newfoundland late on the 18th and early on the 19th. Floyd's extratropical remnant merged with a large extratropical low over the north Atlantic and was no longer a distinct entity by 1800 UTC 19 September.

b. Meteorological Statistics

Table 1 lists the best track positions and intensities at six-hourly intervals. Figure 1 is a display of this track.

Figure 2a, Figure 2b, and Figure 3 depict the best track curves of maximum one-minute average "surface" (10 meters above ground level) wind speed and minimum central sea-level pressure, respectively, as a function of time. Also plotted on Figure 2a and Figure 3 are aircraft reconnaissance and dropsonde data from the U.S. Air Force Reserves (the Hurricane Hunters) and NOAA, estimates from analyses of surface synoptic data, as well as Dvorak-technique estimates from the Tropical Analysis and Forecast Branch, TAFB, the Satellite Analysis Branch, SAB, and the U.S. Air Force Weather Agency (AFGWC in the figures) using satellite imagery. Figure 2b also shows the best track wind speed curve, but with only *in situ* data, i.e. flight level and dropsonde wind measurements. In both Figure 2a and Figure 2b the flight level winds are adjusted for elevation (90% of 700 mb wind speeds, 80% of 850 mb speeds, and 85% of 1500 ft speeds), and dropsonde wind measurements above the surface are adjusted to the 10 meter level using a mean hurricane eyewall profile determined by previous dropsonde measurements.

The peak intensity of Floyd, 135 knots, is based upon roughly 90% of the highest flight level (700 mb) winds of 149 knots at 0933 UTC 13 September. Minimum dropsonde-measured central pressure was 921 mb at 1121 UTC on that date.

Floyd is estimated to have been a 90-knot hurricane at landfall in North Carolina.

There was a 10 meter anemometer measurement of sustained winds of 83 knots at 0710 UTC with gusts to 106 knots at 0716 UTC taken by University of Oklahoma meteorology professor Josh Wurman near Topsail Beach North Carolina. There were also unofficial reports of peak wind gusts to 120 knots (at 8 stories elevation) at Wrightsville Beach and 104 knots at the Wilmington Emergency Operations Center.

Table 2 lists ship reports of tropical storm force or greater wind speeds associated with Floyd. Table 3 lists a selection of surface observations from land stations and data buoys. Floyd's eye passed over NOAA data buoy 41010, located about 105 n mi east-northeast of Cape Canaveral, around 0900 UTC 15 September. That buoy reported maximum 8-minute averaged winds of 72 knots at an anemometer height of 5 meters. At least three factors would imply a higher value for the 1-minute, 10 meter wind speed from the buoy observation: 1) going from an 8-minute to a 1-minute average; 2) going from 5 meters to 10 meters elevation; and 3) the presence of waves over 50 feet high. The best track intensity of Floyd when it passed over the buoy is near 100 knots, as indicated by dropsonde and aircraft flight level wind data. The center of the hurricane passed about 25 n mi west of the Frying Pan Shoals C-MAN station located about 30 n mi southeast of Cape Fear at 0500 UTC 16 September. This station reported winds sustained at 86 knots for a 20-minute period centered at that time, at an anemometer height of 44 meters.

On 13 September, just after Floyd reached maximum strength, there was evidence of a concentric eyewall. Figure 4 is a sequence of microwave images produced by the Naval Research Laboratory. Note that in the first image, during the deepening phase, there was a dominant inner eyewall with an eye diameter of 20 to 25 n mi. Later on, after peak intensity was reached, there was some indication of a concentric eyewall, particularly in the last image of this sequence. It is interesting to note that after this period, there was an apparent eyewall replacement, as suggested in the microwave image sequence shown in Figure 5, and in radar imagery from NOAA/WP-3D aircraft research missions (not shown). It can be seen that the inner eyewall was dissipating while Floyd was centered near Eleuthera. This corresponded to a weakening of the hurricane to near 105 knots. The outer convective ring became the new eyewall by the time Floyd was centered over Abaco, corresponding to an eye diameter near 50 n mi. Afterwards, the new eye failed to contract significantly, while Floyd re-strengthened just slightly as it reached Abaco. After the disintegration of the inner eyewall the large-scale environment, as noted in the previous section, became less favorable. Consequently, after leaving the Bahamas, Floyd never regained its former intensity and, in fact, slowly weakened.

Heavy rainfall preceded Floyd over the mid-Atlantic states due to a pre-existing frontal zone and the associated overrunning. Hence, even though the tropical cyclone was moving fairly quickly, precipitation amounts were very large. Rainfall totals as high as 15 to 20 inches were recorded in portions of eastern North Carolina and Virginia. At Wilmington, North Carolina, the storm total of 19.06 inches included a 24-hour record of 15.06 inches. Totals of 12 to 14 inches were observed in Maryland, Delaware, and New Jersey. New records were set in Philadelphia for the most amount of rain in a calendar day, 6.63 inches. In southeastern New York, rainfall totals were generally in the 4 to 7 inch range but there was a report of 13.70 inches at Brewster. Totals of nearly 11 inches were measured in portions of New England.

Storm surge values as high as 9 to 10 feet were reported along the North Carolina coast.

A number of tornadoes were sighted in eastern North Carolina. There was a confirmed tornado in Bertie County and another in Perquimans County. The latter tornado destroyed two houses and damaged three or four others. At least ten tornadoes were reported by spotters in the Newport/Morehead City County Warning area, and these apparently caused some structural damage. Four tornadoes or funnel clouds were seen in the Wilmington area, but no damage was apparent.

c. Casualty and Damage Statistics

There were 57 deaths that were directly attributable to Floyd, 56 in the United States and 1 in Grand Bahama Island. The death toll by state is as follows: North Carolina 35, Pennsylvania 6, New Jersey 6, Virginia 3, Delaware 2, New York 2, Connecticut 1, and Vermont 1. Most of these deaths were due to drowning in freshwater flooding. Floyd was the deadliest hurricane in the United States since Agnes of 1972.

In the United States, the Property Claims Services Division of the Insurance Services Office reports that insured losses due to Floyd totaled 1.325 billion dollars. Ordinarily this figure would be doubled to estimate the total damage. However, in comparison to most hurricane landfalls, in the case of Floyd there was an inordinately large amount of freshwater flood damage, which probably alters the two to one damage ratio. Total damage estimates range from 3 to over 6 billion dollars.

d. Forecast and Warning Critique

When averaged over the entire lifetime of the hurricane, the track forecasts for Floyd were excellent. Table 4 shows the average track errors for the official forecast and for a selection of objective guidance models. It can be seen that the average official forecast errors were substantially below the most recent ten-year averages. Also, on average, the official forecasts were better than all of the guidance except the UKMI model which had average track errors that were about equal to those of the official forecasts.

Although the *overall* average official forecast errors for Floyd were extremely low, the official forecasts were just ordinary if one considers only the period when hurricane warnings were in effect for the United States,. For example, the average 24-hour track forecast error for the latter period was roughly the same as the most recent ten-year average. Official track forecasts during the latter period also had a westward bias, and were somewhat slow. For example, the 36-hour official track forecasts during the period when hurricane warnings were in effect for the United States were an average of 104 n mi too far west and 70 n mi too far south. All of the track guidance models showed a similar westward and slow bias during this period.

Official intensity forecasts were fairly good (errors of 10 knots or less) for the first couple of days of Floyd's history. However, there were some large underforecasts of intensity, by as much as 30 to 40 knots, from 10-12 September. After Floyd reached its maximum intensity, the official forecasts did not show enough weakening. From 13 September onward, the wind speed was overpredicted in the advisories at practically every forecast time interval, by as much as 30 to 40 knots, and even 50 knots in one occasion. The Statistical Hurricane Intensity Prediction Scheme, SHIPS, performed similarly.

Table 5 is a chronology of the various watches and warnings that were issued for Floyd. A hurricane warning was issued for the northwest Bahamas more than 24 hours prior to the arrival of the eyewall at Eleuthera. For the United States, practically the entire east coast (the greater Miami area northward to Plymouth Massachusetts) was put under a hurricane warning for Floyd. To the authors' knowledge, the last time such an event occurred was during Hurricane Donna of 1960. Hurricane warnings for the southeast Florida coast proved unnecessary. However, given the forecast uncertainty and the required response times for evacuations and other preparations for such a large, severe hurricane, it was prudent to issue such warnings. The hurricane warning was issued for the coast of North Carolina at 0300 UTC 15 September. This is about 26-27 hours prior to the arrival of the eyewall in the Cape Fear area. Generally, for the coasts of South and North Carolina, hurricane warnings were issued at least 24 hours before the onset of tropical storm force winds.

According to preliminary information provided to the Federal Emergency Management agency, over 2 million people were evacuated for Floyd in the United States. This is probably the largest evacuation in U.S. history.

Acknowledgements

Some of the data in this report was furnished by local National Weather Service Offices in Miami, Melbourne, Jacksonville, Charleston, Wilmington, Newport/Morehead City, Raleigh/Durham, Wakefield, Baltimore/Washington, Mount Holly, New York, and Taunton. Stephen Baig produced the track chart, and James Franklin produced the wind and pressure plots.

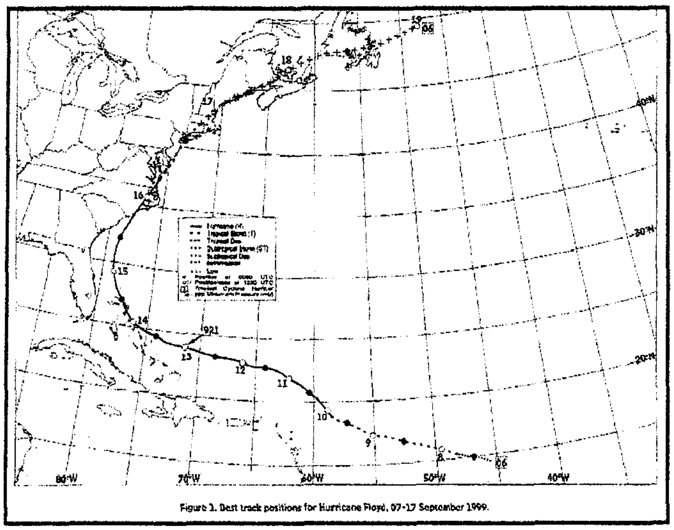


Figure 1. Best track for Hurricane Floyd, 7-17 September 1999.

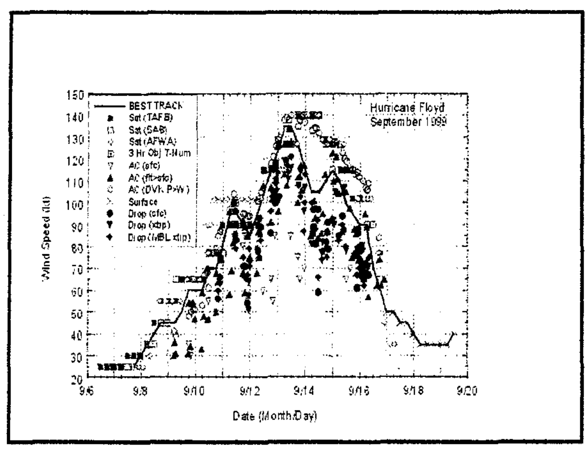


Figure 2a. Best track maximum sustained wind speed curve for Hurricane Floyd, showing all available intensity estimates and wind observations. Aircraft wind measurements have been adjusted for elevation (90% of 700 mb wind speeds, 80% of 850 mb speeds, and 85% of 1500 ft speeds), and dropsonde wind measurements above the surface are adjusted to the 10 meter level using a mean hurricane eyewall profile determined by previous dropsonde measurements. Vertical line denotes landfall.

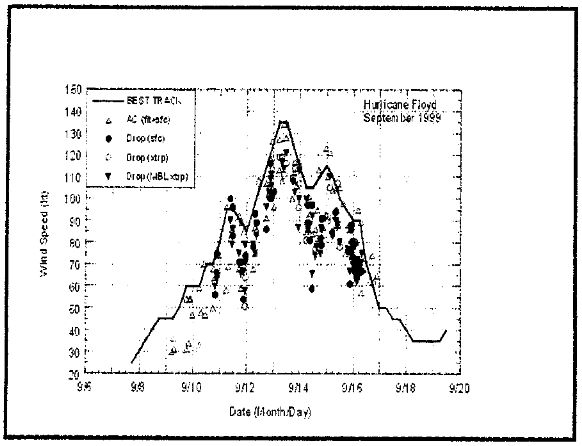


Figure 2b. Best track maximum sustained wind speed curve for Hurricane Floyd, showing only in situ wind observations adjusted for elevation as indicated in Figure 2a.

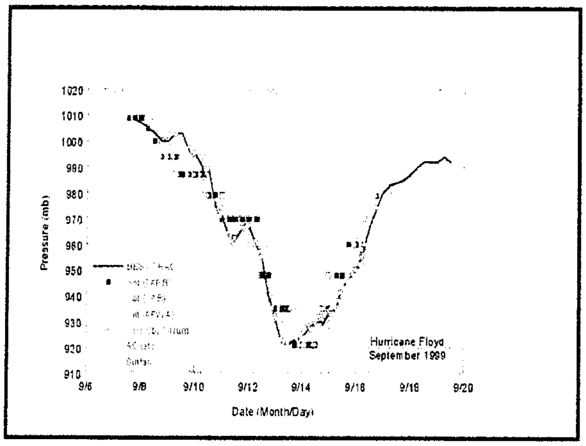


Figure 3. Best track minimum central pressure curve and central pressure observations or estimates for Hurricane Floyd. Vertical line denotes landfall.

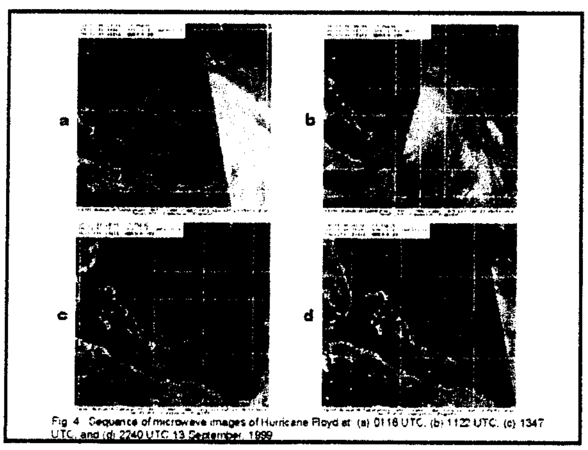


Figure 4. Sequence of microwave images of Hurricane Floyd at: (a) 0116 UTC, (b) 1122 UTC, (c) 1347 UTC, and (d) 2240 UTC 13 September, 1999.

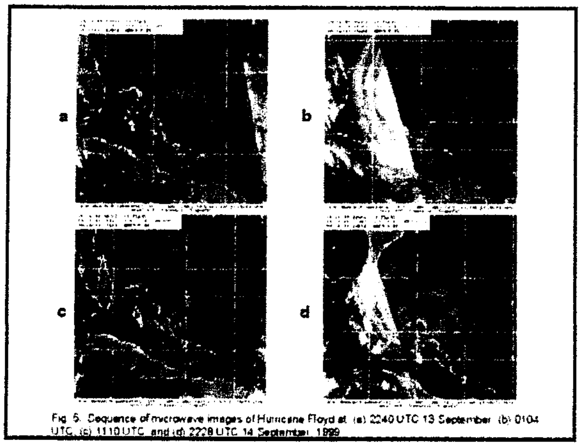


Figure 5. Sequence of microwave images of Hurricane Floyd at: (a) 2240 UTC 13 September, (b) 0104 UTC, (c) 1110 UTC, and (d) 2228 UTC 14 September, 1999.

Table 1. Best track, Hurricane Floyd, 7 - 17 September, 1999

Date/Time (UTC)	Position		Pressure (mb)	Wind Speed (kt)	Stage
	Lat. (°N)	Lon. (°W)			
7/1800	14.6	45.6	1008	25	tropical depression
8/0000	15.0	46.9	1007	30	"
0600	15.3	48.2	1005	35	tropical storm
1200	15.8	49.6	1003	40	"
1800	16.3	51.1	1000	45	"
9/0000	16.7	52.6	1000	45	"
0600	17.1	53.9	1003	45	"
1200	17.3	55.1	1003	50	"
1800	17.9	56.3	996	60	"
10/0000	18.3	57.2	995	60	"
0600	18.6	58.2	990	60	"
1200	19.3	58.8	989	70	hurricane
1800	20.2	59.6	975	70	"
11/0000	20.8	60.4	971	80	"
0600	21.4	61.1	963	95	"
1200	21.9	62.0	962	95	"
1800	22.5	63.0	966	90	"
12/0000	22.7	64.1	967	85	"
0600	22.8	65.2	960	95	"
1200	23.0	66.2	955	105	"
1800	23.2	67.4	940	115	"
13/0000	23.4	68.7	931	125	"
0600	23.6	70.0	922	135	"
1200	23.9	71.4	921	135	"
1800	24.1	72.9	923	125	"
14/0000	24.5	74.0	924	115	"
0600	24.9	75.3	927	105	"
1200	25.4	76.3	930	105	"
1800	26.1	77.0	930	110	"
15/0000	27.1	77.7	933	115	"

0600	28.2	78.5	935	110	"
1200	29.3	78.9	943	100	"
1800	30.6	79.1	947	95	"
16/0000	32.1	78.7	950	90	"
0600	33.7	78.0	956	90	"
1200	35.7	76.8	967	70	"
1800	38.0	75.3	974	60	tropical storm
17/0000	40.6	73.5	980	50	"
17/0600	42.1	72.1	983	50	tropical storm
1200	43.3	70.6	984	45	extratropical
1800	44.2	68.9	985	45	"
18/0000	44.8	67.3	987	40	"
0600	45.4	65.5	990	35	"
1200	46.6	63.0	992	35	"
1800	47.7	59.3	992	35	"
19/0000	48.0	56.3	992	35	"
0600	48.5	52.5	994	35	"
1200	49.5	48.0	992	40	"
1800					merged with low
13/1200	23.9	71.4	921	135	**minimum pressure**
					Landfalls
14/1200	25.4	76.3	930	105	Near Alice Town, Eleuthera
14/1900	26.3	77.1	932	120	Near Cherokee Sound, Abaco
16/0630	33.8	78.0	956	90	Near Cape Fear, North Carolina

Table 2. Ship reports of 34 knots or higher wind speed associated with Hurricane Floyd, September 1999.

Date/Time (UTC)	Ship call sign	Lat. (°N)	Lon. (°W)	Wind dir/speed (deg/kt)	Pressure (mb)
08/1500	**PDYI**	19.0	52.6	070/39	1011.1
09/0900	**DFSO**	17.2	53.7	180/37	1004.2
09/1200	**DFSO**	16.9	54.5	210/37	1005.2
09/1500	**DFSO**	16.6	55.4	180/45	1005.5
12/1500	**DGOO**	22.7	69.3	320/35	1001.5
12/1800	**DGOO**	23.5	69.5	340/37	998.5
12/1800	**ZCAH3**	24.9	63.1	130/58	1009.3
12/2100	**DGOO**	24.1	69.8	030/43	994.8
13/0000	**DGOO**	24.5	69.9	040/45	994.8
13/0300	**DGOO**	24.9	70.3	040/52	997.0
13/0600	**DGOO**	25.6	70.5	040/52	998.5
13/0900	**DGOO**	26.3	70.8	060/52	999.5
13/1200	**DILD**	24.9	53.1	170/37	1013.9
13/1200	**DGOO**	27.0	71.0	090/52	1002.9
13/1800	**KHRH**	19.5	74.7	360/50	994.0

13/1800	**WZJF**	21.3	66.9	135/35	1009.5
14/0000	**PPXI**	30.6	74.3	070/50	1001.0
14/0900	**WGJT**	22.0	73.5	180/35	998.2
14/1200	**PPXI**	30.4	71.0	110/45	1001.0
14/1500	**PEXU**	26.7	70.6	120/37	1009.2
15/0300	**SHIP**	30.3	74.3	100/45	1006.5
15/0900	**DGOS**	29.3	73.8	130/38	1004.0
15/1200	**DGOS**	28.9	73.8	130/47	1003.5
15/1200	**PFKV**	30.6	74.0	120/38	1004.4
15/1800	**PFKV**	30.3	74.0	130/36	1003.6
16/0000	**WRGQ**	31.5	75.4	160/46	(898.1)
16/0300	**PEXU**	29.4	73.9	190/36	1008.5
16/0600	**WRGQ**	31.2	75.2	200/41	1001.0
16/0600	**SHIP**	36.8	73.0	140/36	1006.8
16/1200	**WZJE**	32.0	71.6	180/38	1008.5
16/1200	**3ELL6**	32.0	72.5	200/36	1007.2
16/1800	**BKJO**	34.7	72.2	190/60	1005.0
16/1800	**WZJE**	32.1	72.3	210/52	1009.6
16/2100	**DEDI**	40.4	70.9	130/42	998.0
16/2100	**SHIP**	36.6	69.5	180/47	1007.0
17/0000	**DEDI**	40.4	70.8	140/50	993.3
17/0000	**SHIP**	36.6	68.4	190/40	1009.5
17/0000	**WAUU**	36.0	68.5	190/46	1009.7

Table 3. Hurricane Floyd, selected surface observations, September 1999.

	Minimum sea-level pressure		**Maximum surface wind speed (kt)**					
Location	**Press. (mb)**	**Date/ time (UTC)**	**Sust. wind[a] (kts)**	**Peak gust (kts)**	**Date/ time[b] (UTC)**	**Storm surge[c] (ft)**	**Storm tide[d] (ft)**	**Rain (storm total) (in)**
Bahamas								
Grand Bahama Island	983.0	15/0100	52	65	14/2000		5.27	
Little Harbor Abacos	929.0	14/1910						9.32
Nassau			55	68				
Florida								
Craig Field	994.6	15/1653	37		15/1929			
Daytona Beach	991.8	15/1353	36	60	15/1053			1.23
Fowey Rocks Lighthouse	995.5	14/2300	36	44	14/1600			
Ft. Lauderdale Exec	994.9	14/2253	23	33	15/0653			0.01
Ft. Lauderdale Int'l	994.6	14/2253	25	36	14/2201			0.10
Ft. Pierce	989.5	15/0735	29	43	15/0736			
Gainesville	994.6	15/1653	33		15/1407			
Jacksonville Int'l	995.3	15/1656	40		15/0907			
Lake Worth Pier	993.4	14/2200	32	49	14/1700			

Leesburg	996.4	15/1053	20	27	15/1153			
Melbourne Airport	989.1	15/0900	45	59	15/0501			1.35
Melbourne WFO			32	52	15/0655			
Miami	995.8	14/2256	19	29	15/0322			0.04
Ocala	998.0	15/1035	28		15/1535			
Orlando	993.8	15/0853	24	42	15/0853			1.26
Patrick AFB (COF)			49	57	15/0820			
Sanford			25	37	14/2024			3.20
Tamiami Airport	996.4	14/2253	21	31	14/1953			
West Palm Beach	992.9	15/0453	27	38	14/1941			0.38
Georgia								
Alma	999.7	15/`950	28		15/1746			
Brooklet								0.41
Dover								0.40
Ludowici								0.52
Newington								0.85
Rocky Ford								0.20
Savannah Airport			35	46	15/1810			
St. Simon's Island	993.2	15/1804	40		15/1804			
South Carolina								
Allendale								0.67
Beaufort								1.83
Charleston City Office			50	74	16/0150			3.99
Charleston Harbor							10.1	
Charleston Int'l Airport	989.5	15/0052	44	58	16/0046			3.91
Edisto Beach State Park			33	47	16/0029			
Florence Airport	991.2	16/0655	36	54	16/0158			4.04
Folly Beach			47	62	15/2300			
Grand Strand	977.0	16/0553		57	16/0523			
Ladson Oakbrook								4.30
Myrtle Beach Airport	979.7	16/0553		62	16/0455			16.06
Myrtle Beach Springmaid Pier				68	16/0500			
Ridgeville								3.58
St. George								1.90
Walterboro								2.50
Williams								2.42
North Carolina								
Beaufort	976.0	16/0409	42	58	16/0405			5.56
Castle Hayne 2E				81	16/0715			
Castle Hayne 3SW				104	16/0845			
Cherry Point MCAS	961.4	16/0555	56	71	16/0405			3.27
Elizabeth City	968.5	16/1418	34	56	16/1346			2.65
Federal Point				97	16/0620			
Flemington				80	16/0625			
Frisco	983.8	16/0740	51	61	16/0805			0.34
Greenville				51	16/0800			
Holden Beach			42	64	16/0820			

Manteo				53	16/1000			
Masonboro Island							10.3	
Mt. Olive				65	16/0520			
Myrtle Grove				89	16/0540			
Newport				58	16/0454			
New Bern	961.1	16/0543	39	58	16/0501			4.29
New River	959.0	16/0426	44	68	16/0556			8.26
Oak Island			52	69	16/0820		10.0	
Pleasure Island							10.0	
Rocky Mount/Wilson Airport								15.15
Seymour Johnson AFB	983.0	16/0955	45	60	16/1055			
South River								3.50*
Washington				41	16/0800			
Wilmington Airport	959.7	16/0755	54	75	16/0855			19.06
Wilmington Corning Plant				89	16/0700			
Wilmington EOC				104	16/0845			
Wrightsville Beach				120				
Virginia								
Fort Eustis	985.2	16/1455	25	37	16/1640			
Glouchester								11.25
Hampton								7.50
James City County								14.30
Langley AFB			40	55	16/1355			
Lower James City								12.83
Newport News	983.4	16/1558	33	44	16/1623			16.57
Norfolk Airport	977.1	16/1551	27	40	16/1303			
Norfolk NAS	979.1	16/1555	38	48	16/1609			
Oceana NAS	975.7	16/1556	35		16/1656			
Portsmouth	978.3	16/1600	30	52	16/1614			10.10
Richmond	991.9	16/1640	29	44	16/1405			6.54
Smithfield								12.50
Wakefield WFO								12.73
Weems								10.83
Yorktown								
Maryland								
Annapolis								11.60
Cambridge							2.5	
Chestertown								14.00
Lewisetta							3.5	
Martin State Airport	989.0							
Mid-Bay Buoy				60	16/1710			
Ocean City	976.8	16/1853	31	45	16/1653			1.71
Patuxent NAS	991.0		30	36	16/1555			
Salisbury	980.4	16/1851	28	42	16/2150			5.08
Solomon's Island							3.0	
St. Inigoes	987.6							
Tall Timbers				62	16/2040			11.10
Thomas Point Light			43	49	16/1300			

Delaware								
Cape Henlopen				56	16/PM			
Greenwood								10.58
Lewes						2.6	6.76	
Vernon								12.36
Wilmington	986.0	16/2106	32	40	16/2214			
New Jersey								
American Corners								10.20
Atlantic City	980.2	16/2054	23	34	16/2345	2.0	6.22	
Caldwell/Essex Co. Airport	987.8	16/2353		38	16/2353			10.21
Cape May						2.6	7.36	
Doylestown								10.07
Federalsburg								11.20
Neshanic								10.07
Newark Int'l Airport	985.1	16/2351	38	46	16/2351			6.22
Pequannock								11.04
Sandy Hook	981.0	16/2306	34	45	17/0024	1.9	6.57	
Somerville								13.34
Teterboro Airport	985.0	16/2351	24	38	16/2351			8.53
Wayne/Iflows								12.21
White House								12.98
Pennsylvania								
Philadelphia	985.0	16/2136	32	42	16/2136	2.8	9.34	
New York								
Central Park	983.8	16/2250	25	36	16/1450			5.02
Farmingdale Airport	981.6	16/2353	23	37	16/2053			3.13
HPN Airport	985.8	17/0050	25	42	16/2350			6.26
Islip/MacArthur Airport	983.4	17/0156	27	37	16/2356			
JFK Int'l Airport	982.5	16/2351	30	41	17/0051			3.27
LaGuardia Airport	983.7	16/2351	30	41	17/0051			4.94
MGJ Airport			29	44	16/2039			
MTP Airport	986.9	17/0254	22	37	17/0454			
Newburgh/Stewart Airport	992.6	17/0045	34	54	16/2245			
NWS Upton								3.50
Westhampton Airport	984.8	17/0153	28	43	17/0153			
White Plains Airport	985.8	17/0050	25	42	16/2350			
Massachusetts								
Beverly				31				
Blue Hill Observatory-Milton				40				
Boston							10.7	
Boston/Logan Airport				38				
Brewster				63	17/0545			
Buzzards Bay			47	57	17/0300			
Fox Point Hurricane Barrier						4.2		
Hadley								9.60

Hyannis				62				
Lawrence				32				
Martha's Vineyard				34				
Nantucket				32			1.3	
New Bedford Hurr. Barrier				64	17/0600	2.5		
Norwood				27				
Orange				29				
Plymouth				33				
Southwick								9.16
Taunton				38				
Westfield				37				
Worcester				30				
Rhode Island								
Block Island				39				
Newport				35			2.6	
Providence				35			5.9	
Westerly				31				
Connecticut								
Bridgeport Airport	981.8	17/0154	29	39	16/2254			
Bristol								10.80
Burlington								9.45
Danbury Airport	987.1	17/0153	15	21	17/0153			
Groton/New London Airport	986.8	17/0145	30	43	17/0045			
Hartford Airport	985.4	17/0253						
Meriden	984.5	17/0156						
MMK Airport	986.4	17/0155	20	34	17/0155			
New Haven Airport	983.8	17/0145	33					
Southington								9.14
Willimantic	985.8	17/0352		31				
Windsor Locks				37				
New Hampshire								
Manchester				28				
NOAA National Data Buoy Center buoys								
41004 (30.5N 79.1W)			54	72	16/0200			
41009 (28.5N 80.2W)	980.9	15/0900	52	70	15/1000			
41008 (31.4N 80.9W)			24	31	15/2100			
41010 (28.9N 78.5W)	939.6	15/0900	72	91	15/0700			
44009 (38.5N 74.7W)	976.0	16/1900	39	52	16/1800			
44014 (36.8N 74.8W)	981.4	16/1600	50	66	16/1615			
44025 (40.3N 73.2W)	980.0	17/0000	33	43	17/0600			
NOAA National Data Buoy Center C-MAN stations								
BUZM3 (41.4N 71.0W)			47	57	17/0300			
CLKN7 (34.6N 76.5W)	974.9	16/0500	63	79	16/0450			
DSLN7 (31.2N								

75.3W)	985.8	16/0730	69	82	16/0750			
DUCN7 (36.2N 75.8W)	977.0	16/0900	67	83	16/0850			
FPSN7 (33.5N 77.6W)	958.7	16/0600	86	97	16/0512			
SAUF1 (29.9N 81.3W)	992.9	15/1200	58		15/1200			

[a]ASOS and C-MAN are 2 min; buoys are 8 min.
[b]Date/time is for sustained wind when both sustained and gust are listed.
[c]Storm surge is water height above normal astronomical tide level.
[d]Storm tide is water height above National Geodetic Vertical Datum (1929 mean sea level).

Table 4. Preliminary forecast evaluation of Hurricane Floyd, heterogeneous sample. (Errors in nautical miles for tropical storm and hurricane stages with number of forecasts in parenthesis).

Forecast Technique	Period (hours)				
	12	24	36	48	72
CLIP	40 (35)	88 (33)	148 (31)	206 (29)	312 (25)
GFDI	36 (34)	71 (32)	97 (30)	115 (28)	153 (25)
GFDL*	31 (30)	66 (30)	96 (28)	109 (26)	155 (24)
LBAR	30 (34)	59 (32)	92 (30)	112 (28)	120 (24)
AVNI	38 (35)	77 (33)	119 (31)	141 (29)	187 (25)
BAMD	37 (34)	70 (32)	106 (30)	147 (28)	239 (24)
BAMM	50 (34)	96 (32)	137 (30)	175 (28)	243 (24)
BAMS	63 (34)	123 (32)	173 (30)	207 (28)	263 (24)
A98E	35 (33)	72 (31)	113 (29)	120 (27)	174 (24)
NGPI	39 (29)	69 (27)	101 (25)	123 (23)	146 (19)
UKMI	29 (32)	54 (30)	66 (26)	76 (24)	97 (21)
NHC OFFICIAL	28 (35)	53 (33)	73 (31)	73 (29)	104 (25)
NHC OFFICIAL 1989-1998 10-year average	48 (2005)	89 (1790)	128 (1595)	164 (1410)	242 (1107)

* GFDL output not available until after forecast issuance.

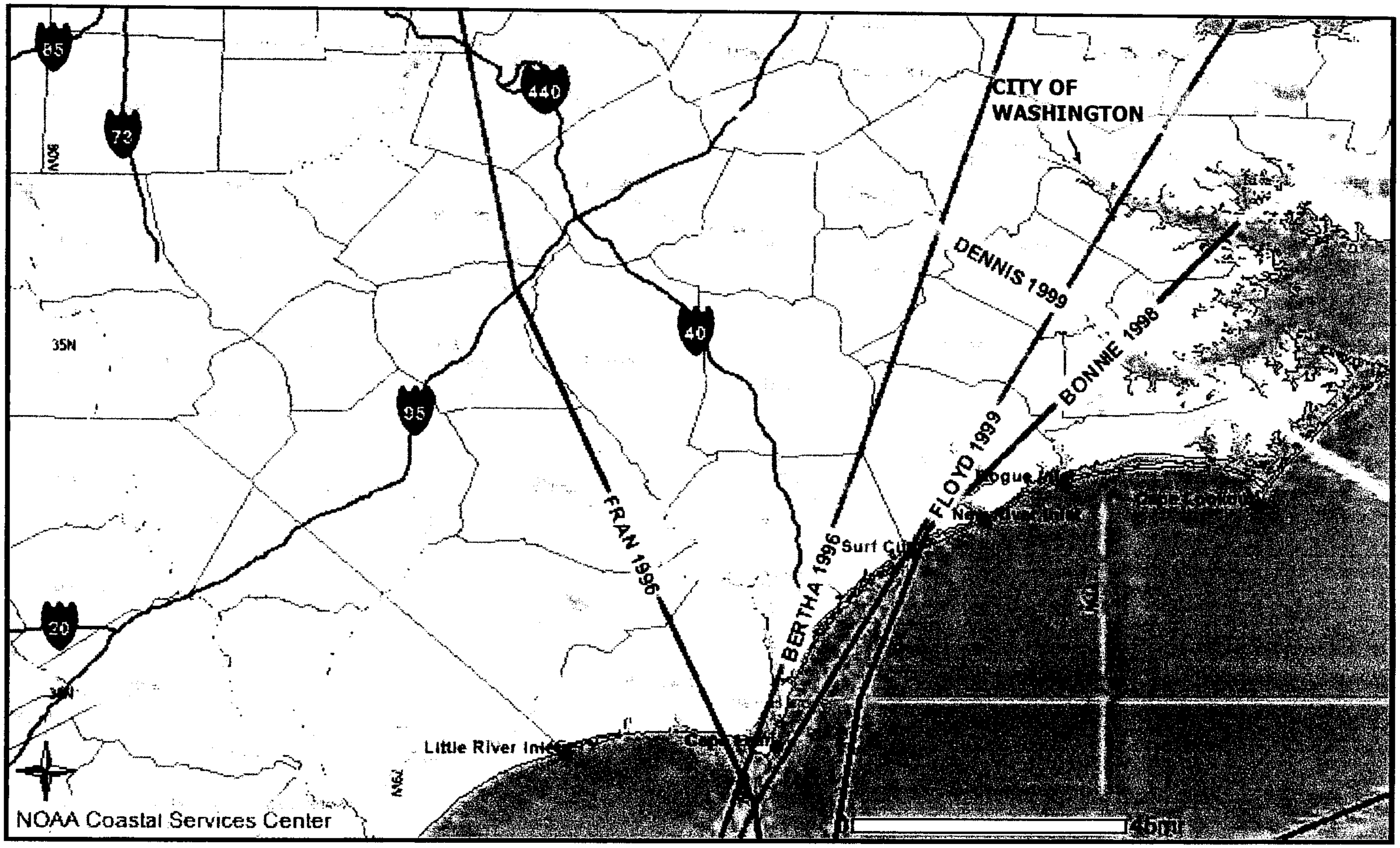
Table 5. Watch and warning summary, Hurricane Floyd, September 1999

Date/Time (UTC)	Action	Location
09/2100	Tropical storm watch issued	Antigua, Barbuda, Anguilla, and Dutch Saint Maarten
09/2200	Tropical storm watch issued	French Saint Martin and Saint Barthelemy
11/0300	Tropical storm watch discontinued	Antigua, Barbuda, Anguilla and Dutch Saint Maarten
11/0300	Tropical storm watch discontinued	French Saint Martin and Saint Barthelemy
12/0900	Tropical Storm warning and hurricane watch issued	Turks, Caicos, and Southeast Bahamas
12/0900	Hurricane watch issued	Central Bahamas

13/0000	Hurricane warning issued	Central Bahamas
13/0000	Hurricane watch issued	Northwest Bahamas
13/0900	Hurricane watch upgraded to hurricane warning	Northwest Bahamas
13/0900	Hurricane watch issued	Florida: South of Flagler Beach to Hallandale
13/1500	Hurricane watch extended	South to include Miami-Dade County and north of Flagler Beach, Florida to Brunswick, Georgia
13/1800	Hurricane watch extended	Including Lake Okeechobee
13/2100	Hurricane watch upgraded to hurricane warning	Florida City, Florida to south of Brunswick, Georgia
13/2100	Tropical storm warning issued	Florida Keys, north of Seven Mile Bridge
13/2100	Hurricane watch issued	Georgia: Brunswick to Savannah
14/0300	Hurricane watch extended	North of Savannah, Georgia to Little River Inlet, South Carolina
14/0900	Tropical storm warning discontinued	Turks and Caicos Islands
14/1500	Tropical storm warning discontinued	Southeast Bahamas
14/2100	Tropical storm warning discontinued	Florida Keys, from the Seven Mile Bridge northward
14/2100	Hurricane warning extended	Georgia and South Carolina coasts to Little River Inlet, South Carolina
14/2100	Hurricane warning downgraded to tropical storm warning	Florida: Florida City to Boca Raton
14/2100	Hurricane watch extended	North of Little River Inlet, South Carolina to Cape Charles Light, Virginia, south of New Point Comfort, including Pamlico and Albermarle sounds
15/0300	Hurricane warning extended	North of Little River Inlet, South Carolina to the North Carolina/Virginia border
15/0300	Hurricane warning discontinued	Florida: Boca Raton to Ft. Pierce
15/0300	Hurricane watch extended	North Carolina/Virginia border to Chincoteague, Virginia, including Chesapeake Bay, south of Smith Point
15/0300	Hurricane warning discontinued	Central Bahamas
15/0300	Tropical storm warning discontinued	Florida: Florida City to Ft. Pierce
15/0600	Hurricane warning discontinued	Northwest Bahamas: New Providence, Bimini, Andros, and Berry Islands
15/0900	Tropical storm watch issued	Chincoteague, Virginia to Cape Henlopen, Delaware, including Chesapeake Bay north of Smith Point and the Potomac from Cobb Island to Smith Point
15/1200	Hurricane warning discontinued	Florida: South of Sebastian Inlet to Ft. Pierce Northwest Bahamas: Grand Bahama and Abaco Islands
15/1500	Hurricane warning discontinued	Florida: Sebastian Inlet to Titusville
15/1500	Tropical storm watch extended	North of Chincoteague, Virginia to Sandy Hook, New Jersey, including Delaware Bay
15/1700	Tropical storm watch extended	North of Sandy Hook, New Jersey to Montauk Point on Long Island, New York, including Delaware Bay
15/1900	Hurricane warning discontinued	Florida: Titusville to Fernandina Beach
15/2100	Hurricane warning extended	North of North Carolina/Virginia border to Chincoteague, Virginia, including Chesapeake Bay, south of Smith Point
15/2100	Tropical storm watch upgraded to tropical storm warning	North of Chincoteague, Virginia to Sandy Hook, New Jersey, including northern Chesapeake Bay, the Potomac Basin, and Delaware Bay

15/2100	Tropical storm watch extended	North of Sandy Hook, New Jersey to the Merrimack River, Massachusetts, including Long Island Sound
16/0300	Hurricane warning discontinued	North of Fernandina Beach, Florida to Edisto Beach, South Carolina
16/0300	Hurricane warning extended	North of Chincoteague, Virginia to Cape Henlopen, Delaware
16/0300	Tropical storm warning extended	North of Sandy Hook, New Jersey to Plymouth, Massachusetts
16/0900	Hurricane warning extended	North of Cape Henlopen, Delaware to Manasquan Inlet, New Jersey and from Moriches Inlet, New York to Plymouth, Massachusetts
16/0900	Tropical storm warning extended	North of Plymouth, Massachusetts to Merrimack River, Massachusetts
16/1100	Hurricane warning discontinued	From South Santee River, South Carolina, southward
16/1300	Hurricane warning discontinued	South Santee River, South Carolina to Surf City, North Carolina
16/1500	Hurricane warning discontinued	North Carolina: North of Surf City to Cape Hatteras
16/1800	Hurricane warning discontinued	Cape Hatteras, North Carolina to Cape Charles Light, Virginia, including southern Chesapeake Bay
16/2100	Hurricane warning downgraded to tropical storm warning	Cape Charles Light, Virginia to the Merrimack River, Massachusetts, including Chesapeake Bay, the Potomac Basin, Delaware Bay, and Long Island Sound
17/0300	Tropical storm warning discontinued	Cape Charles Light, Virginia to Sandy Hook, New Jersey, including Chesapeake Bay, the Potomac Basin, and Delaware Bay
17/0900	Tropical storm warning discontinued	Sandy Hook, New Jersey to the Merrimack River, Massachusetts, including Long Island Sound

North Carolina Hurricane Tracks for 1996 to 1999



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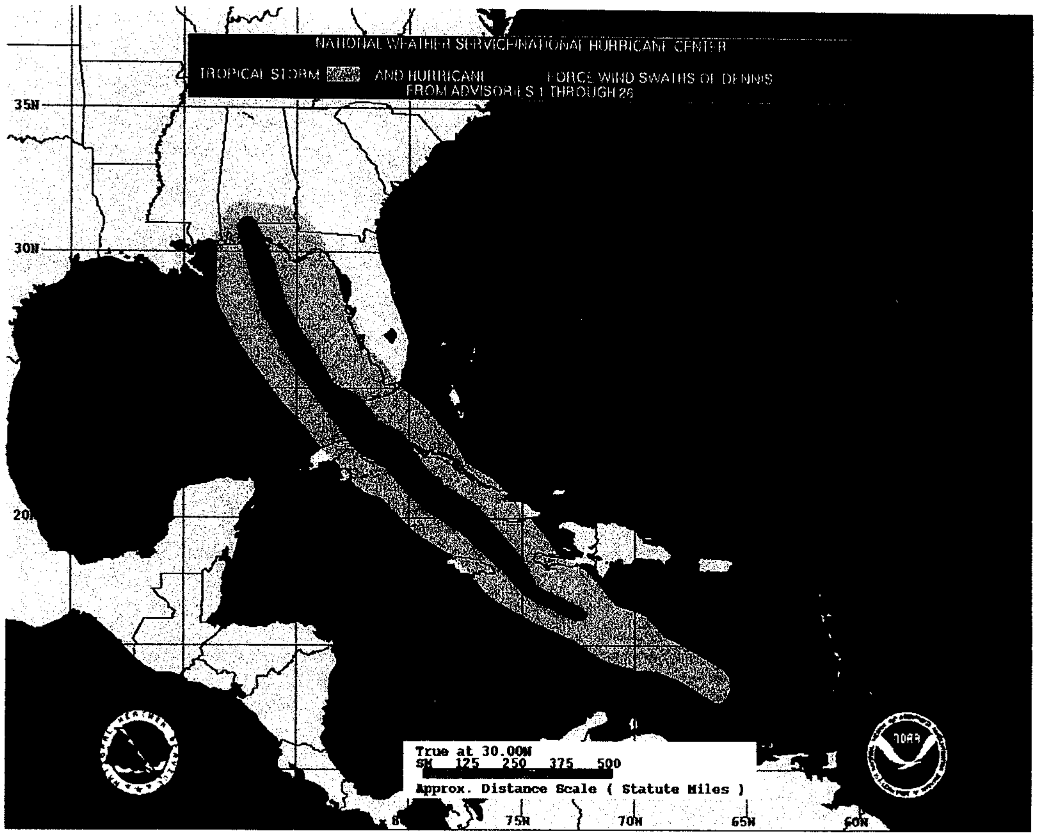

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