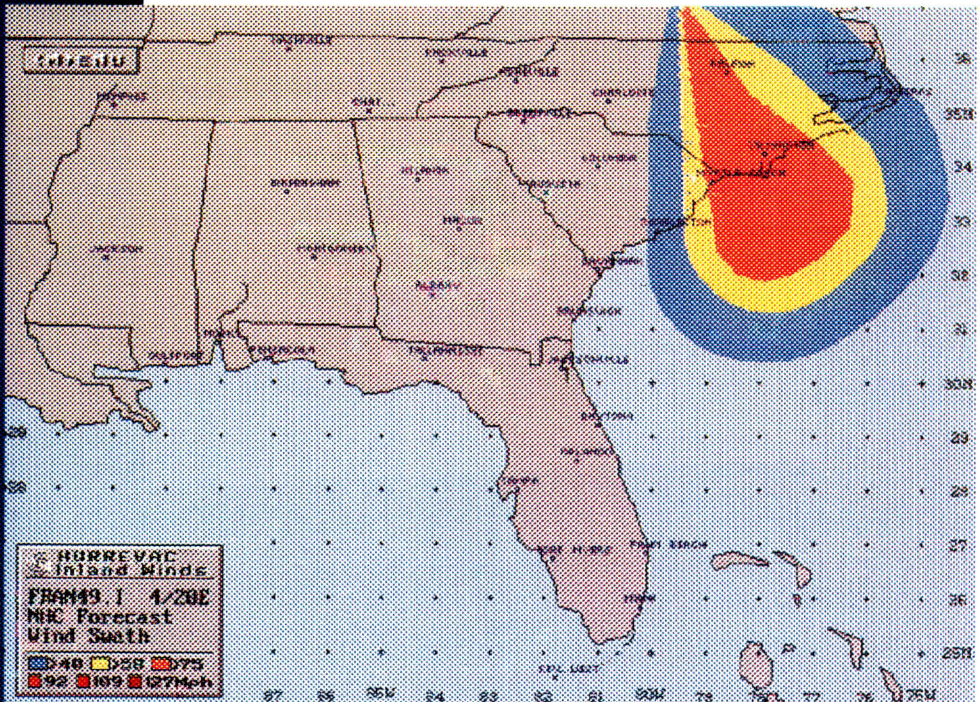
JUNE 19, 1997



Study of Inland Wind Effects of Hurricane Fran and Assessment of Inland Wind Model

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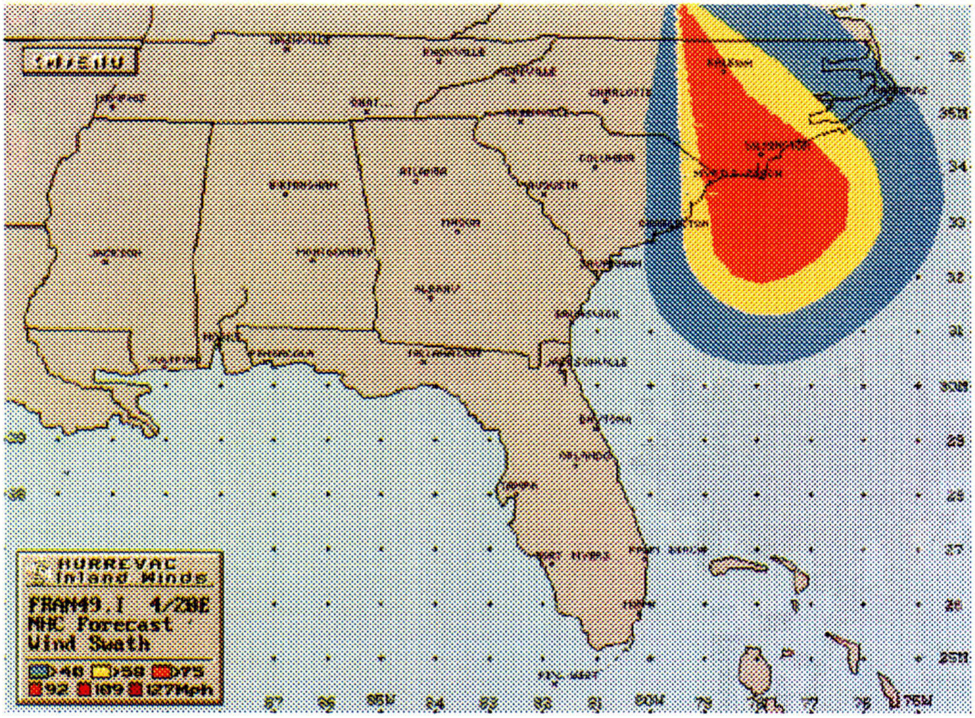
COVER ILLUSTRATION:

Wind Swath shown by the Inland Wind Display Model for Hurricane Fran at marine advisory no. 49, the last advisory issued before the storm's landfall on September 5, 1996.

JUNE 19, 1997



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1 INTRODUCTION

1.1 Background

Hurricane Fran made landfall east of Cape Fear, North Carolina, at approximately 8:00 p.m. daylight savings time on September 5, 1996. The maximum sustained wind speed at the time of landfall was estimated by the National Weather Service (NWS) National Hurricane Center (NHC) to be approximately 115 miles per hour (mph). The maximum storm surge was reported to be approximately 12 feet. The storm was classified a Category 3 hurricane on the Saffir-Simpson Scale.

Information about the storm's winds is still being compiled by the Hurricane Research Division (HRD) of the National Oceanic and Atmospheric Administration (NOAA). NOAA will not issue its findings for several more months.

The effects of the storm were felt far into Virginia, Maryland, West Virginia, and Pennsylvania. While wind gusts were greater than 50 mph in Richmond, Virginia, the primary effect in the inland areas north of North Carolina was extensive rain and flooding. Fran was responsible for a total of 26 deaths in South Carolina, North Carolina, Virginia, West Virginia, Maryland, and Pennsylvania (see Appendix A).

Damages from the storm have not yet been totaled, as claims for damage are still being submitted. It is estimated that damage costs will exceed $3 billion. A total of 34 counties in North Carolina were declared eligible for public assistance programs.

1.2 Purpose

Under contract to FEMA, Greenhorne & O'Mara, Inc., (G&O) conducted an investigation to evaluate the damages resulting from inland winds associated with Hurricane Fran, verify and standardize the recorded wind data for Hurricane Fran, compare wind information displayed by FEMA's Inland Wind Display Model (hereafter referred to as the Inland Wind Model) with the recorded wind data, and ultimately assess the ability of the model to accurately display inland wind speeds. Section 5 of this report describes the development and purpose of the Inland Wind Model. Information about both wind and wind-induced damage was collected from many sources for North Carolina and Virginia, the two states most severely affected by Fran. Although emphasis was placed on inland communities, the first step for this study was obtaining wind information for coastal communities.

The investigation included collecting wind speed and wind damage data, conducting site visits to assess storm damage over the two-state affected area, contacting a large number of people who had pertinent information, and analyzing the information to compare the effects of Hurricane Fran with those of other inland hurricane wind events. As a supplement to this technical report, a slide presentation was prepared that summarizes G&O's findings, conclusions, and recommendations. In addition, a Descriptive Reference Guide (DRG) was prepared (see Table 4.2) that categorizes the damages associated with various wind fields.

FEMA expects that State and county emergency managers will be able to use the Inland Wind Model to predict the types of damage that may result from a particular inland wind event and to help FEMA and other organizations such as utilities, schools, churches, and the American Red Cross prepare for the expected damages. It is also expected that the use of the model will aid in the development of standard operating procedures for inland areas that can be used during severe storm events.

1.3 Organization of the Report

This report presents an overview of Hurricane Fran, a description of the investigation, a discussion of FEMA's Inland Wind Model and the predictive version developed by the NHC, and a detailed review of actual wind speeds and the predicted effects of various wind fields. A comparison of predicted and recorded wind data provides the basis for conclusions and recommendations concerning predicting wind speeds, estimating the expected damages, and undertaking mitigation measures that can enhance building performance under gale-force wind, storm-force wind, and hurricane conditions. The DRG (Table 4.2) can help emergency management personnel predict the effects of strong inland winds.

Supporting data, including site visit summaries, anemometer data, damage data, and wind model output information, are provided in appendixes. Tables, photographs, figures, and maps are used throughout this report to present findings and illustrate the conclusions and recommendations.

2 INVESTIGATION

2.1 Information Sources

Numerous sources of information pertaining to Hurricane Fran were contacted, including Federal and local government agencies, military airfields, and emergency response organizations. The types of sources contacted are as follows:

- local government emergency management agencies
- U. S. Park Service personnel
- U. S. Air Force and Marine airfields
- fire departments
- NWS
- U. S. Bureau of the Census
- American Red Cross
- utility companies
- universities
- regional newspapers
- meteorologists
- business sites
- the Internet

The sources were contacted by telephone, mail, or in person to obtain relevant information. The NWS and county emergency managers provided wind and damage data and identified other potential information sources. U. S. Park Service personnel provided GIS maps of wind-induced tree damage and other information pertaining to the storm. The NWS, military and commercial airfields, and "weather watching" citizens provided wind measurements taken during the storm and descriptions of wind damage to buildings and infrastructure.

Newspapers proved a valuable source of local coverage of damage sustained during Fran. Wind data were collected primarily from NWS stations and the Internet. The U. S. Census Bureau provided population information and a breakdown of residential structures by type. Universities, including forestry departments and agricultural extension services, were also contacted for information. The American Red Cross provided most of the statistical information on structural damage.

2.2 Site Visits

The investigation was begun within 2 weeks after the occurrence of Hurricane Fran, and information about wind-induced damages had to be collected within a short period. It was determined that the best way to obtain the necessary information under these conditions was to conduct site visits in selected portions of Virginia and North Carolina, the two states most severely affected by the hurricane. The areas visited were those where damage was still visible or where other valuable information was available, including photographs or an anemometer that provided wind speed information.

First, an intensive information gathering effort was conducted to determine where the most significant damage occurred, then two travel routes were selected for the site visits. The routes were selected for one or more of the following reasons: anemometers used in the collection of recorded wind speeds were nearby, damage from Fran was still visible and accessible, photographs of damage were available for review on-site, a significant event was reported to have occurred along the route (e.g., an unusual recorded wind speed), or the route approximated the actual storm track through the two states.

Two G&O employees conducted the site visits. More than 30 sites were inspected, and over 600 miles traveled within an area extending northeast from Wilmington to Durham, North Carolina, and from Martinsville, Virginia, to Washington, DC. Figure 2-1 shows the site visit travel routes, including stops made along the routes. Summaries of the site visits are provided in Appendix B.

Figure 2-1   Site visit travel routes.

3 WIND MEASUREMENTS

3.1 Wind Speed Measurements

The reporting of wind speed measurements for Hurricane Fran was as inconsistent as the reporting of wind speed measurements for other recent high-wind events. Also, as in other events, the measurements were provided in many formats. For a discussion of wind speed reporting methods, see FEMA's report *Study of Inland Wind Effects of Hurricane Opal and Assessment of Inland Wind Model,* dated October 7, 1996.

An additional difficulty with wind speed verification is that the reports from weather reporting stations are sent to the National Climatic Data Center (NCDC) at the end of every month for archiving. If the wind speed information is not retrieved before this archiving begins, the records become inaccessible for a period of several months, until they are available from the NCDC information retrieval system. Most of the wind speed information for this report was retrieved either directly from reporting stations or from weather stations through the Internet.

The reporting of recorded wind speeds during Hurricane Fran used several different averaging times. Consequently, the recorded wind speeds must be normalized before they can be compared with the results of computer-generated models. Wind speeds were reported as hourly means, 10-minute means, 2-minute means, and 1-minute means at fixed times; maximum 10-minute means, 2-minute means, and 1-minute means; peak gusts; and gusts at fixed times.

Most recordings are taken on the hour, so unless special attention is being paid to the wind recordings, the recorded speeds may be the last 2-minute average just prior to the hour, the peak during the hour, the highest peak of the day, or the true highest 10-minute mean during the hour. Normalization of the data requires determining how the speeds are measured. Automated Surface Observing System (ASOS) stations provide a "Summary of the Day" that includes the maximum 2-minute average recorded and the maximum 5-second wind (also referred to as the "peak gust"). Other stations have similar summary reporting systems but may use different averaging times, e.g., 10-minute means, highest peak gust.

Normalization of the wind data also requires adjusting the speed to a standard anemometer height of 33 feet above the ground. Most ASOS stations now have wind sensors at the standard 33-foot height, but most military stations have sensors at a height of either 13 feet or 20 feet. The heights of sensors located on light towers and CMAN stations vary greatly. Therefore, anemometer information, including the height of the sensor, must be obtained for each station. This information can be obtained from the station, the NCDC, or the Internet.

Normalization of the wind data also requires that the exposure of the wind measurement station be evaluated. The standard exposure is defined in the American Society of Civil Engineers (ASCE) Standard *Minimum Design Loads for Buildings and Other Structures* (ASCE 7-95) as Exposure C, which is "open terrain with scattered obstructions having heights generally less than 30 ft (9.1 m)." ASCE 7-95 further states that "This category includes flat open country and grasslands." For this investigation, ocean exposure wind recordings were reduced by 20 percent to obtain wind speeds normalized to Exposure C. The normalization process is important because it provides a more accurate basis for comparing wind speeds recorded in different locations.

Recorded peak gusts were adjusted for averaging time, anemometer height, and exposure to obtain a "normalized" 1-minute sustained wind speed. This normalized sustained wind speed was then compared to the adjusted sustained wind speed at each location, and a judgment was made about which wind speed should be used in this analysis -- the adjusted peak gust or the adjusted sustained wind. See Table 4.1 and Appendix C for additional information.

Several references were used to normalize the wind speeds, including a procedure outlined by Mark Powell, Sam Houston, and Tim Reinhold in a September 1996 paper written for The American Meteorological Society journal *Weather and Forecasting*. The title of the paper is "Hurricane Andrew's Landfall in South Florida, Part I, Standardizing Measurements for Documentation of Surface Wind Fields." Formulas used for the standardization in this investigation were developed from ASCE 7-95 and the paper referred to above in consultation with Dr. Peter Sparks, a wind engineering expert. The formulas are presented in the list of notes for the table in Appendix C.

In general, the following data were available from which to construct the sustained and gust wind fields for Hurricane Fran:

(a) data from NWS stations with ASOS equipment and fully commissioned ASOS stations that operated throughout the storm -- accurate measurements of the maximum 2-minute wind and maximum 5-second wind

(b) data from military bases with "hot-wire" type anemometers that operated throughout the storm -- accurate measurements of the maximum 2-minute wind and the maximum 5-second wind (Adjustments to the standard anemometer height were necessary.)

(c) data (of varying accuracy) from other sources

The original recorded data and the adjusted data are shown in Table 4.1, in Section 4.

3.2 The Saffir-Simpson Scale, Beaufort Scale, and Damage Potential

The most widely used damage potential scale for hurricanes is the Saffir-Simpson Scale. A description of this scale, excerpted from the *National Hurricane Operations Plan* issued by the Office of the Federal Coordinator for Meteorological Services and Supporting Research, is provided in Appendix D. That document includes an interesting definition of a sustained wind: "...one that persists for the minimum time period to establish optimal dynamic forces on a nominal building structure." For a typical house, this period is only a few seconds. Indeed, Saffir, writing a report for the United Nations in 1975, clearly stated that his wind speeds refer to gusts of 2 to 3 seconds.

At some point, the meteorological sustained wind speed (taken by most of the world to be a 10-minute average wind speed) and the structural sustained wind speed (a 2- to 5-second average speed) became confused with the conventional way of measuring the sustained wind in the United States, i.e., observing a wind speed indicator for 1 minute. The net result was the Saffir-Simpson Scale in the form now used by the NHC to classify hurricanes. In the Saffir-Simpson Scale, a sustained wind speed is taken to be a 1-minute average wind speed. As can be seen from Table 4.1, there is a considerable difference between a 1- or 2-minute average wind speed and a peak gust wind speed.

The starting point for the proposed DRG (see Table 4.2) is the Beaufort Scale used by NWS to estimate "sustained" wind speeds. This scale was developed in Europe for storms with little convective activity and whose sustained and peak gusts have a relatively fixed ratio. Although the Beaufort Scale is intended to be used with 10-minute mean speeds, the assumption has been made that because it is an approximate scale, it can also be used with the 2-minute wind recorded by an ASOS station.

Sometimes in hurricanes, and usually when mean wind speeds are quite low and thunderstorms are present, thermally induced convection will produce unusually high gusts. Very often these peak gusts are not associated with the highest mean speed in the storm. While such gusts may produce local damage, they are isolated events and not typical of general wind conditions.

To overcome this problem of extreme local gusts, the Beaufort Scale has been modified to include both the maximum 2-minute wind and the maximum 5-second wind. The 2-minute average probably gives a better indication of widespread effects. If the maximum 5-second wind exceeds the maximum 2-minute wind by more than 30 percent, this is usually an indication of convective effects. Using the 5-second wind in these circumstances will give an indication of potential damage, but the damage is likely to be localized. The more extreme the 5-second wind, the more localized the damage is likely to be. For example, the maximum 2-minute sustained wind reported by the ASOS station at Raleigh was 52 mph, but the maximum 5-second wind was 79 mph. The speed differences were exactly the same at Cherry Point Marine Base. The damage at both locations was severe in localized areas.

Since the Beaufort Scale is open-ended for hurricane conditions, the Saffir-Simpson Scale intervals have been used to subdivide the hurricane category for this investigation. It has been assumed that the nominal 1-minute sustained wind is equivalent to the maximum 2-minute wind. Since NHC uses the maximum sustained wind anywhere in the storm to categorize a hurricane, and the Beaufort Scale refers to wind conditions at a particular location, using the terms "Category 1," "Category 2," etc. is considered unwise. Therefore, in this report the classes of hurricane have been given separate names.

The expected damage, as shown in the DRG (Table 4.2), is based upon the original Beaufort Scale, the Saffir-Simpson Scale corrected to the form originally intended by Saffir, and observations of the effects of Hurricanes Frederic, Hugo, Andrew, and Opal.

4 HURRICANE FRAN

4.1 Recorded Wind Speeds

The maximum sustained wind speeds and peak wind gusts associated with Hurricane Fran are shown in Table 4.1. The recorded sustained speeds have been adjusted for height and have been adjusted to 1-minute sustained speeds in Exposure C in accordance with the discussion in Section 3.1 of this report. The recorded peak gusts have been adjusted for height. The recorded data provide a representative picture of the inland effects of this hurricane.

Figures 4-1 and 4-2 show the sustained and peak gusts plotted on a map of the affected area. The boundaries of the wind field areas have been interpolated between the reporting stations shown on the maps. Recorded wind speeds from stations reporting throughout the storm have been used. In addition, damage observed along the site visit travel routes was used as an indication of wind speed. The legends for the maps correlate to the Beaufort Scale and gale-force, storm-force, and hurricane-force conditions. The lower wind speed value in Figure 4-2 (47 mph) represents a strong gale-force wind on the Beaufort Scale and was chosen as the lower boundary because 40-mph peak gusts were prevalent throughout the entire states of North Carolina and Virginia.

The maximum adjusted sustained wind speed over water associated with this storm has been found to be 92 mph at Frying Pan Shoals, a CMAN station approximately 40 miles offshore of Cape Fear, North Carolina. The highest recorded sustained wind speed onshore from a fully functioning station is 75 mph at New River Marine Air Base, just South of Jacksonville, North Carolina. This station is approximately 15 miles inland at the mouth of the New River, which feeds directly into the Atlantic Ocean just North of Topsail Beach and Surf City.

Other wind speeds were reported from non-standard sites along the coastline. An anemometer mounted 4 feet above the chimney of a house located 2.5 miles inland of Wrightsville Beach recorded an 80-knot (92-mph) "sustained" wind speed. A Radio Shack anemometer mounted on top of a catamaran mast at Wrightsville Beach recorded an 87-knot (100-mph) sustained wind speed. The wind speeds from these anemometers were not verified for this report. A professional-quality anemometer mounted 33 feet above the ground at Kure Beach recorded a 66.6-mph hourly average, which is approximately equivalent to an 85-mph sustained wind speed.

Near the time of landfall, reconnaissance aircraft recorded a flight-level (10,000 feet) wind speed of 105 knots. Reducing the flight-level speed of 105 knots (121 mph) by 20 percent as suggested in Section 3.1 yields a sustained surface wind speed of 97 mph. This value correlates very well with the recorded speeds along the coast but is lower than the 115-mph reported wind speed at landfall.

Table 4.1 Recorded and Adjusted Wind Speeds

STATION	RECORDED SUSTAINED WIND SPEED (MPH) [1]	RECORDED PEAK GUST (MPH)	ANEMOMETER HEIGHT (FEET)	PEAK GUST WIND SPEED ADJUSTED TO 1 MIN. AVG.	BEST ESTIMATE OF SUSTAINED WIND SPEED (MPH) [2]	ADJUSTED PEAK GUST (MPH)[3]	PRIMARY WIND DIRECTION	RAINFALL TOTAL (IN.)
Frying Pan Shoals [4]	99	124	145	92	74	88	E	
Wilmington, NC [5]	67	86	33	68	68	86	E	4.41
Southport, NC		105	33 [A]	88	70	84		
New River MCAS, NC	67	94	20	75	75	98	E	7.05
Cherry Point, NC	49	76	20	62	62	79	E	2.12
Cape Lookout, NC	64	82	32	68	55	66	SSE	
Kure Beach, NC	67	95	33	73	73	95		
Cape Hatteras, NC	44	56	32	47	38	56		
Holden, NC		77	33 [A]	64	51	62		
Myrtle Beach, SC		75	32 [A]	63	50	75		7.02
Pope AFB, NC	49	67	13	57	57	72	NNW	6.72
Ft. Bragg, NC	44	74	20 [A]	61	58 [7]	77	NNE	4.70
Seymour Johnson AFB	63	80	13	68	70	87	E	6.38
Raleigh-Durham, NC [5]	45	79 [8]	33	62	54 [7]	79	NE	8.80
Greensboro, NC	35	48	20	40	40	50	NW	3.91
Greenville, NC		100 [9]		79	~ 59	100 [9]		
Rocky Mount/Wilson, NC	20	45		36	[10]		SSW	3.68
Elizabeth City, NC	43	55		43	43	55		
Norfolk, VA [11]	30	46	33	45	45	46		.46
Danville, VA	46	63	33 [A]	50	50	63		
Richmond, VA [5]	37	53	33	42	42	53		1.81

Table 4.1 Recorded and Adjusted Wind Speeds

STATION	RECORDED SUSTAINED WIND SPEED (MPH) (1)	RECORDED PEAK GUST (MPH)	ANEMOMETER HEIGHT (FEET)	PEAK GUST WIND SPEED ADJUSTED TO 1 MIN. AVG.	BEST ESTIMATE OF SUSTAINED WIND SPEED (MPH) (2)	ADJUSTED PEAK GUST (MPH)(3)	PRIMARY WIND DIRECTION	RAINFALL TOTAL (IN.)
Lynchburg, VA (5)	25	44	20 (A)	36	36	46	SSE	
Wintergreen, VA		41	30	32	32	41		10.72
Virginia Power-Louisa, VA	33	43	33	34	34	43	SE	
Dulles Airport, VA (5)	29	40	33 (A)	32	32	40	E	

Notes:

(1) Averaging time is given if known; otherwise, it is the highest reported sustained wind.

(2) Best estimate obtained by comparing results of two estimation methods: (1) adjustment of recorded sustained wind speed to 1-minute sustained speed at the standard 33-foot anemometer height for Exposure C (over land at airports) and (2) adjustment of the recorded peak gust speed down to a 1-minute sustained wind speed. See Appendix B for all adjustments and calculations.
Because of the variation in averaging times, the adjustment of the peak gust down to the 1-minute sustained condition was usually selected as the "best estimate." If the ratio of gust speed to sustained speed exceeded 1.3, the adjusted sustained wind speed was usually selected as being more representative of sustained conditions.

(3) Speeds adjusted to the standard 33-foot anemometer height and exposure C.

(4) Sustained wind speeds are maximum 10-minute averages.

(5) Sustained wind speeds are maximum 2-minute averages.

(6) Maximum hourly average

(7) Best estimate is 1.2 x sustained winds, because gust factor is so large.

(8) Highest reported speed on hourly readouts was 67 mph. This 79-mph speed was reported by the NWS office in Raleigh, NC.

(9) Wind speed is unconfirmed.

(10) Reported speed not included. Station appears to have not reported throughout storm.

(11) Speeds are an average of those from six reporting stations in the area. All speeds are within 9 mph of the average speed.

(A) Assumed

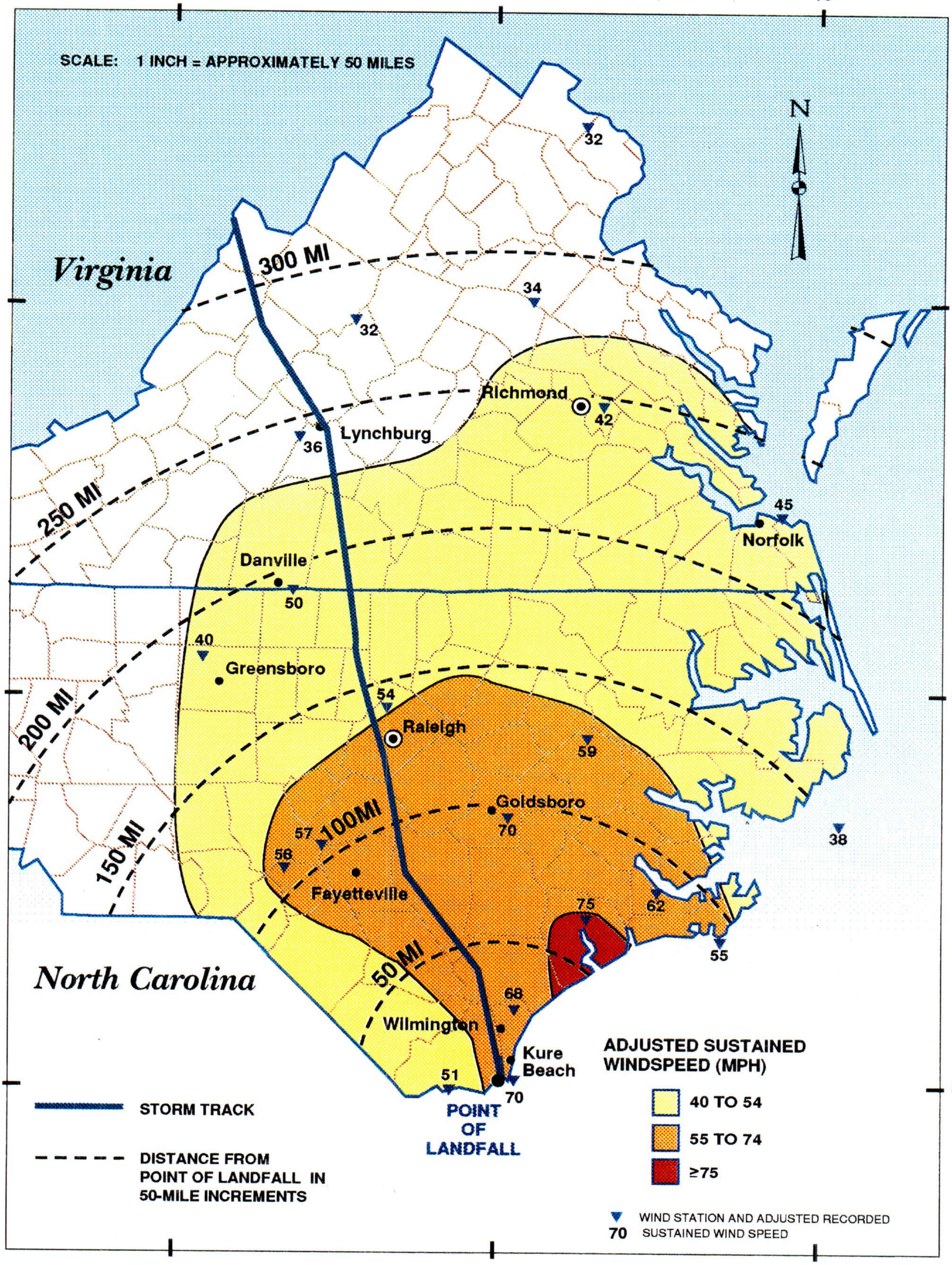


Figure 4-1 Adjusted sustained wind speeds.

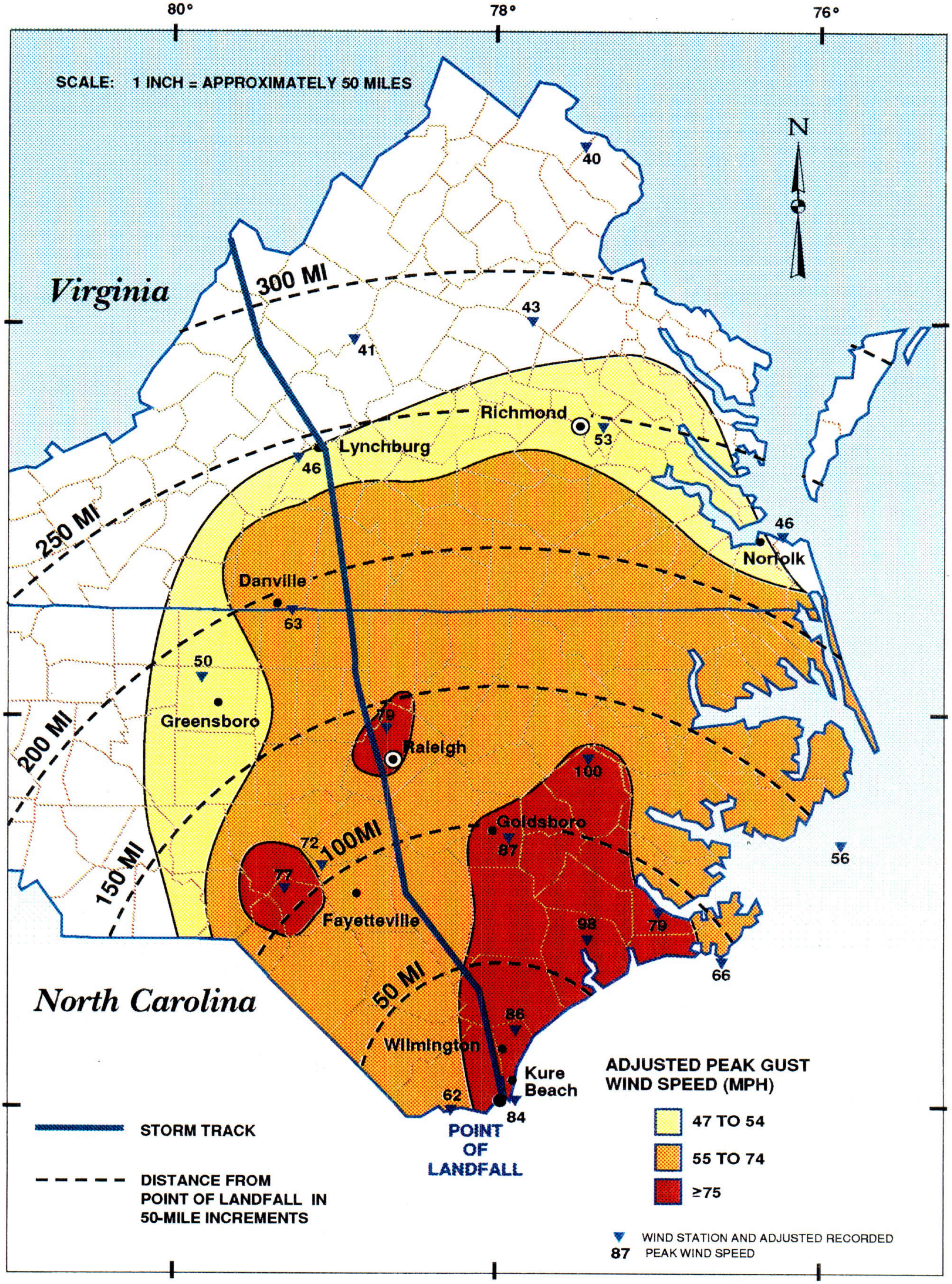


Figure 4-2 Adjusted peak gust wind speeds.

The conclusion from these wind speed data is that the 1-minute sustained wind speed over water at the time of landfall was probably between 90 and 100 mph. A storm with wind speeds in this range would be a Category 2 hurricane on the Saffir-Simpson Scale. The peak gusts along the coast appear to have reached 110 to 120 mph.

Significant convective activity occurred as far north as Seymour Johnson AFB, North Carolina, (85 miles inland) and Raleigh (125 miles inland). This activity created wind gusts of 87 mph near the air base and 79 mph in Raleigh. The thunderstorms at the base were approximately 35 miles east of the storm track. Doppler radar showed 100-knot winds over the base. Gust speeds of 87 mph would be normal with 115-mph (100-knot) winds aloft. Figure 4-3 is a radar image that shows the rain bands near the base at 4:18 UTC.

4.2 Building Codes/Damage Relationship

The North Carolina State Building Code (hereafter referred to as the Code) is the primary code document used in North Carolina. For residential construction in coastal areas, additional standards are imposed that are intended to prevent damage to structures from high-wind and storm surge events. The Code was adopted in the mid-1960's in response to several devastating storms that struck the North Carolina coast in the 1950's. The portion of the Code that dealt with coastal construction required that structures be elevated above recorded high water marks and that a "hurricane" connection be used at every other roof rafter or truss to connect the roof system securely to the structure.

The pile embedment required in the 1965 version of the Code was 8 feet below existing grade. The piles were primarily 8-inch diameter creosote- or pressure-treated poles. A major Code revision was completed in 1986 that required piles be driven 5 feet below mean sea level or a total of 16 feet below grade, whichever is less. The pile material is now primarily 8-inch-square pressure-treated posts. Many of the structures that failed as a result of storm surge from Hurricane Fran were built prior to 1986 and were supported on piles whose embedment depth was inadequate. Although the wind design standards for the main wind-force-resisting systems have been upgraded, no additional wind-resistance requirements have been developed for roof coverings or exterior cladding or for temporary building envelope protection. The design wind speed in the 1986 Code is the 100-mph fastest mile wind speed. Revisions to the Code have been made since 1986.

The 100-mph fastest mile wind speed used in the 1986 Code has a recurrence interval of 50 years. Wind speed map revisions completed since 1986 place most of the coastal counties in the 110-mph fastest mile wind zone. This

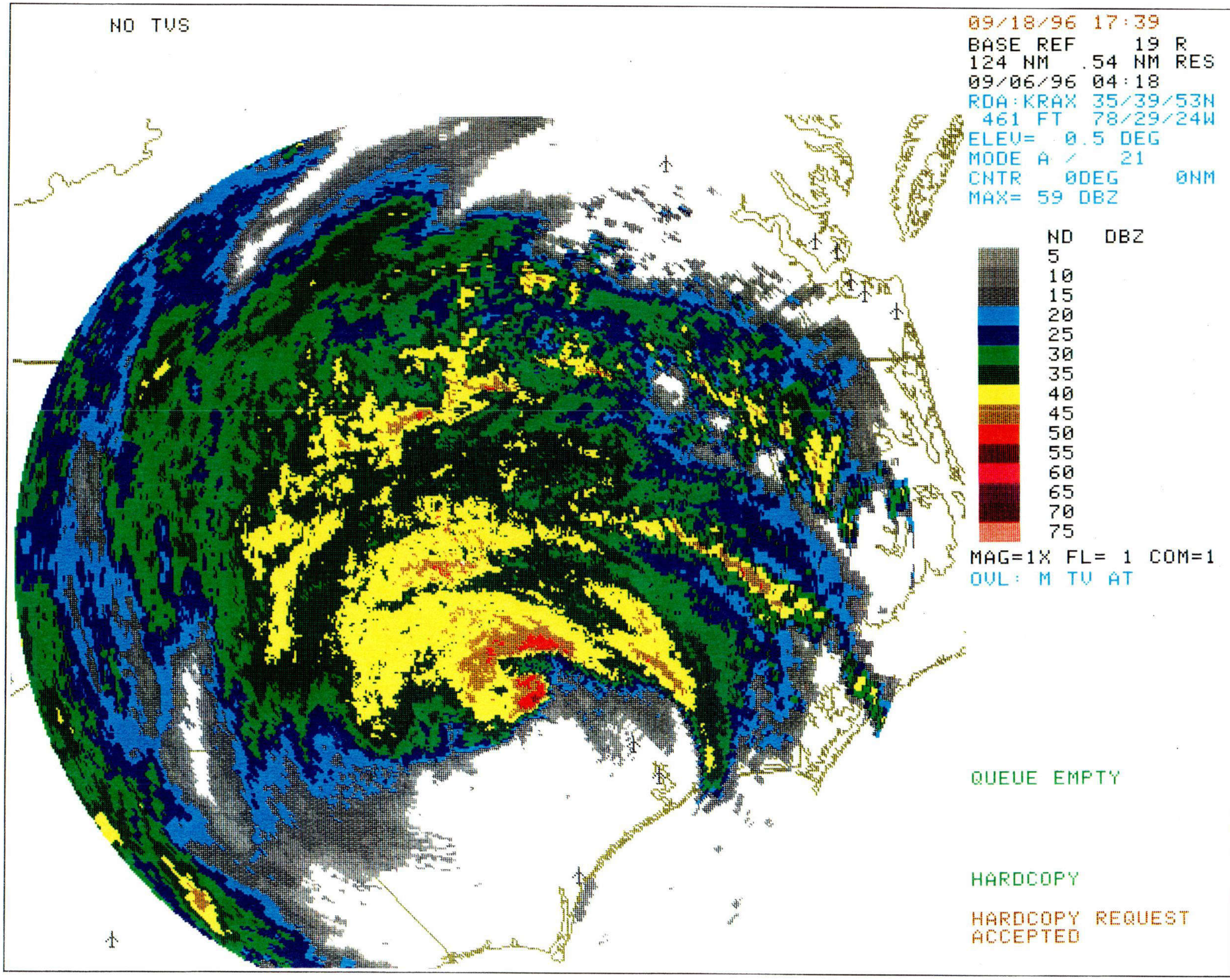


Figure 4-3 Radar image recorded by Doppler radar, 4:18 UTC, September 6, 1996.

wind speed can be equated to approximately a 1-minute sustained wind speed of 107 mph. A review of the adjusted actual speeds in Table 4.1 and a comparison of those speeds with a 107-mph sustained wind indicates that Hurricane Fran was approximately a 25- to 50-year event at the coastline. The highest recorded sustained speed at the coast perhaps reached 100 mph.

ASCE 7-95 wind speeds are expressed as peak gusts. The wind speed map from ASCE 7-95 is shown in Figure 4-4. The map isotachs for the North Carolina coast indicate that the 50-year peak gust is expected to be approximately 125 mph (as interpolated between the 120-mph and 130-mph isotachs). The peak gusts approximately 125 miles inland are expected to be approximately 90 mph. A comparison of these figures with the figures in Table 4.1 indicates that, according to the ASCE 7-95 standard, Hurricane Fran was approximately a 25- to 50-year event in the inland areas.

The DRG shown in Table 4.2 describes expected levels of damage from various wind fields. The DRG was developed from wind speed/damage relationships based on observations made after Hurricane Opal, from damage descriptions in the Beaufort and Saffir-Simpson Scales, and from the storm histories of Hurricanes Frederic, Erin, Andrew, Hugo, and others. It is reasonable to expect that structures built in North Carolina prior to the state's adoption of wind-related code requirements in the mid-1960's would incur levels of damage greater than those described in the DRG. Structures built after the mid-1960's, but before the 1986 revision of the Code, can be expected to incur levels of damage approximately equal to those described. Structures built after the 1986 Code revision, which added more stringent wind-resistance requirements, would probably incur lower levels of damage.

4.3 Wind Speed/Damage Relationships

The DRG can be used by emergency managers to predict the consequences of high-wind events, and it can be used to verify wind speeds, particularly at the coast. It also provides a basis of comparison for structural performance. It is expected that as code provisions and construction techniques improve building performance in high-wind events, the structural damage from high winds would decrease.

Another way to evaluate the wind speeds from Hurricane Fran is to compare the actual damage to coastal structures with the expected damage described in the DRG. Figures 4-5 through 4-11 are photographs that represent structural damage to buildings along the coast from Southport, North Carolina, north to Surf City, North Carolina. The caption of each figure includes a reference to a sustained wind speed category in the DRG so that the damage shown in the photograph can be compared with the damage described.

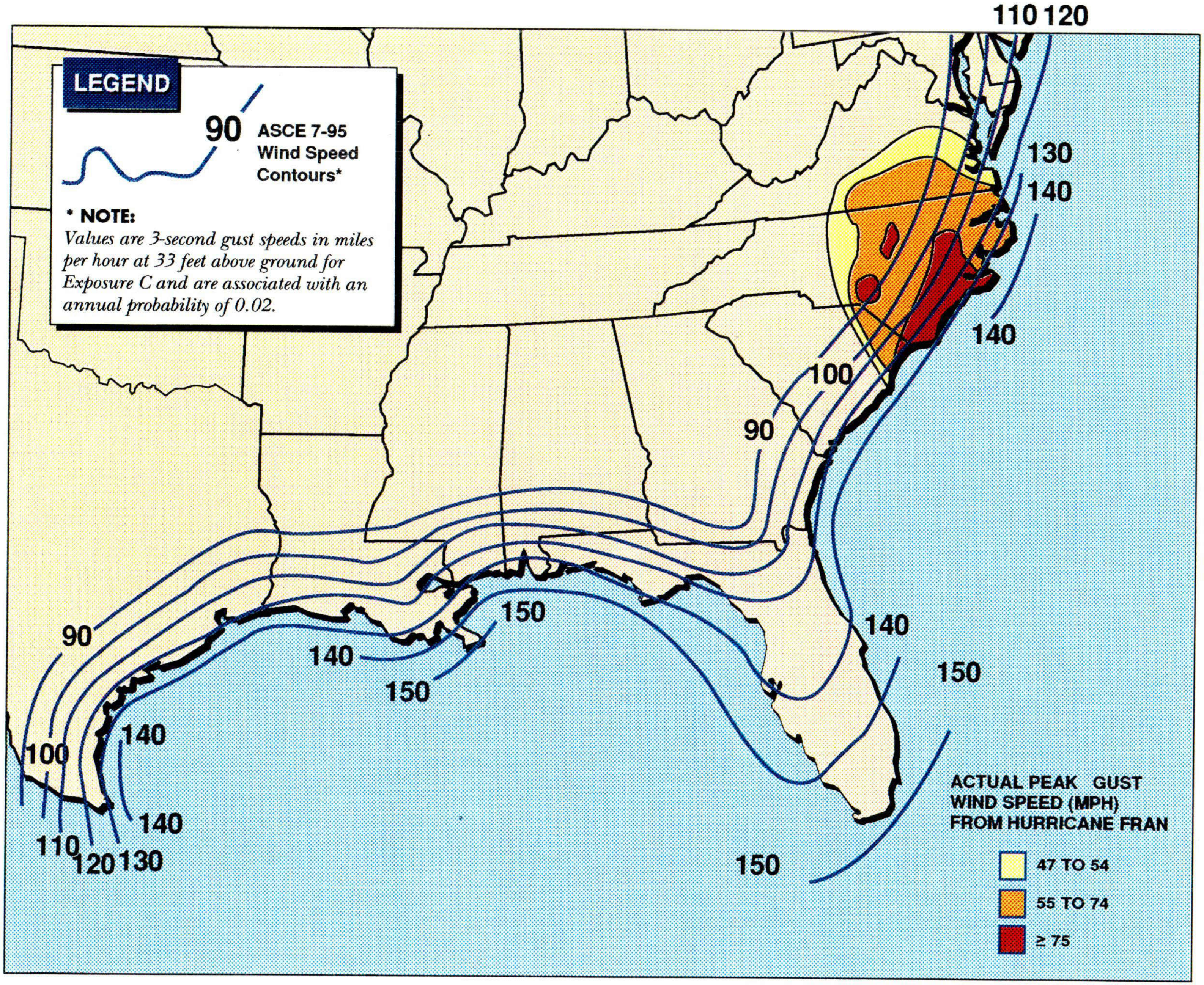


Figure 4-4 *Inland extent of actual peak gusts from Hurricane Fran superimposed on portion of ASCE 7-95 wind speed map.*

Table 4.2 **Descriptive Reference Guide**

SUSTAINED WIND (MPH)	PEAK GUST (MPH)	EFFECTS
39 - 47 (Gale)	50 - 60	• Twigs broken off trees • Progress impeded
47 - 54 (Strong Gale)	61 - 70	• Slight structural damage occurs • 15 - 30 percent of power will be out • Minor wind blown debris • Falling limbs cause minor power outages • Difficult to walk in the wind
55 - 63 (Storm)	71 - 80	• Shallow-rooted trees blown over • Falling trees cause structural damage • Downed trees block roads • Power outages on order of 20 - 40 percent occur • Power outages affect hospitals and shelters • Power outages affect water and wastewater treatment facilities • Small stones (¾-inch diameter) can be moved by the wind • Some sign damage occurs • Insurance claim ratio less than 20 percent • Average insurance loss less than 0.2 percent of insured value
64 - 74 (Violent Storm)	81-95	• Small stones (¾-inch diameter) can become airborne • Roof damage begins to occur • Power outages on order of 40 - 70 percent occur • Power outages affect additional critical care facilities • Power outages completely shut down most water and waste treatment facilities • Tree damage is significant • Difficult to stand up in the wind • Some manufactured homes overturned • Damage to unanchored manufactured homes • Damage to signs, canopies, porches, etc. • Insurance claim ratio 20 percent - 70 percent • Average insurance loss 0.2 - 2.0 percent

Table 4.2 Descriptive Reference Guide (continued)

SUSTAINED WIND (MPH)	PEAK GUST (MPH)	EFFECTS
75 - 95 (Hurricane)	96 -125	• Damage begins to occur to building envelopes, particularly windows and doors; most damage caused by windblown debris • Damage occurs to signs, canopies, porch roofs, and overhangs • Foliage blown off trees • Structural damage to small buildings • Large stones (1½-inch diameter) can be moved by the wind • Gravel on ballasted roofs scours; some flat roof damage occurs • Power outage is 70 percent, shutting down all water, wastewater, and critical care facilities • Insurance claim ratio 70 - 100 percent • Average insurance loss 2 - 10 percent
96 - 110 (Strong Hurricane)	126 -145	• Major structural damage occurs to manufactured homes • Extensive damage to signs, overhangs, canopies, etc. • Large stones (1½-inch diameter) can become airborne • Major damage begins to occur to building envelopes, particularly windows and doors • Extensive roof damage • Major sections of flat roofs are damaged or lost • Some curtainwall failures • Infrastructure is crippled by downed trees and power lines • Wind can move heavy objects such as signs, trash cans, sections of buildings or building materials • Insurance claim ratio ~100 percent • Average insurance loss 10 - 60 percent
>111 (Extreme Hurricane)	>146	• Significant damage occurs to roofing materials and building envelopes, structural failures are prevalent • Some structural damage occurs to small buildings • Manufactured homes are destroyed • Average insurance loss >60 percent

Figure 4-5 Damage to exterior cladding and minor roof damage. (DRG reference: 75- to 95-mph sustained wind speed)

Figure 4-6 Roof shingle damage (arrow). (DRG reference: 75- to 95-mph sustained wind speed)

Figure 4-7 Mobile home destroyed. (DRG reference: 75- to 95-mph sustained wind speed)

Figure 4-8 Major roof damage. (DRG reference: 96- to 110-mph sustained wind speed)

Figure 4-9 Extensive roof damage. (DRG reference: 96- to 110-mph sustained wind speed)

Figure 4-10 Major section of flat roof damaged. (DRG reference: 96- to 110-mph sustained wind speed)

Figure 4-11 Major section of low-sloped roof lost and wall imploded on pre-engineered metal building. (DRG reference: 75- to 95-mph sustained wind speed)

The conclusion based on the observed damage is that the 1-minute sustained wind speed at the coastline was approximately 100 mph.

Inland structures are frequently more protected from the effects of wind than structures on the coast. The more irregular terrain in inland areas and the surface friction caused by the ground features not only reduce the wind speed but generally change the effects of the storm from damage by direct impact of the wind on the structure to collateral damage to structures caused by trees and power lines pushed over or broken by the wind.

Most residential and light commercial structures are less than 30 feet to 40 feet tall. As a result, the tops of the structures are usually below surrounding wind obstructions, including tall trees. This sheltering appears to limit most wind-induced residential roof damage to shingle loss. Overhangs, inadequately attached porch or carport roofs, parapets, and other building elements that can be lifted, pushed, or pulled by the wind are also potential losses.

In areas of open terrain (e.g., areas near most airports, large fields), wind can move closer to the ground surface, where it can increase in speed and cause greater structural, roof, and exterior cladding damage to exposed buildings. In these areas, there is also a greater likelihood of debris becoming airborne and causing collateral damage by penetrating building envelopes. An additional problem at airports is that many buildings (e.g., hangers) are higher than 30 feet to 40 feet and are therefore more vulnerable to wind damage.

Wind damage to infrastructure is normally the result of power loss. High winds will push over or break trees and cause them to fall across power lines. Wind can also break power distribution poles. A loss of power affects water and wastewater distribution and handling systems. In many hurricanes, substantial amounts of rain can flood wastewater treatment plants and shut them down, even when the plants have emergency power. Power loss will also affect critical care facilities such as hospitals and shelters.

Power outages on the order of 70+ percent can be expected when sustained wind speeds reach hurricane force (75 mph).

Vegetation loss from wind is a function of the combination of wind speed, profile of surface obstructions, amount of rain associated with the storm, and type of vegetation. Entire trees will come down if there has been enough rain to soften the soil around their root structures. Broadleaf trees are particularly susceptible to wind damage because the leaves act like sails, catching the wind and helping it push the tree over. The likely failure mode of deep-rooted trees (e.g., pine trees) is breaking of the trunk part way up the tree. Crops in inland areas can be destroyed by winds that tear their leaves off or break their stalks. Crops near the coast can be destroyed by wind-driven salt water as well the direct effects of wind.

Heavy rain can be associated with a landfalling hurricane, as occurred in Hurricane Fran. The months prior to this storm had been generally wet in the storm-affected area. Therefore, the ground was already damp, the water runoff was immediate during the storm, and the runoff channels quickly flooded. Fran caused flooding far into West Virginia, Virginia, and Pennsylvania. The rainfall totals do not appear to follow the pattern of the wind fields. The storm had significant convective activity inland as evidenced by the differences between the sustained and gust wind speeds in both Raleigh and Fayetteville, North Carolina.

4.4 Structural Damage

Structural damage information was obtained for single-family dwellings, mobile homes, apartments, and commercial and public buildings. Appendix E provides a summary by state and county of the percentages of single-family dwellings, mobile homes, and apartments that suffered major damage or were destroyed. Structures defined as having major damage include those that can be made habitable through repairs. These data were assembled from information provided by the American Red Cross and FEMA.

4.4.1 Single-Family Dwellings

Damage to single-family dwellings from wind can be classified as primarily either roof surface/roof structure damage caused directly by the wind or collateral damage caused by wind-damaged trees. Most major roof damage, as represented by Figures 4-5, 4-6, 4-8, and 4-9, occurred along the coast. Minor roof surface loss, as shown in Figures 4-12 and 4-13, occurred in inland areas. Figure 4-12 shows a metal roof rolled back from the edge by wind that came from the southeast. The building in this photograph is located in the Wilmington, North Carolina, area, east of the Cape Fear River. Sustained wind speeds at the Wilmington airport reached 68 mph. Figure 4-13 shows shingles lost from a hip roof that had been installed over existing shingles. This building is north of Goldsboro, North Carolina, where sustained winds reached approximately 70 mph.

Winds with sustained speeds of near 77 mph in Jacksonville, North Carolina, lifted up many carport roofs, porch roofs, and other inadequately attached overhangs and building accessory structures.

Figure 4-12 Metal roof rolled back by wind.

Figure 4-13 Loss of shingles on hip roof.

Trees caused collateral damage along the entire path of the storm as far north as South Boston, Virginia. Figure 4-14 represents tree-caused structural damage in South Boston, Virginia. Sustained wind speeds in Raleigh reached 54 mph. In Danville (near South Boston and Martinsville), the sustained speed was 50 mph. The peak gusts in both locations were between 40 percent and 50 percent higher than sustained winds, again indicating the presence of convective activity and severe thunderstorms.

Figure 4-15 compares the structural damage percentages by county for single-family dwellings in North Carolina and Virginia with the peak gust wind fields illustrated in Figure 4-2. Note there are only four counties with damage levels in excess of 1 percent. Three of these counties are on the Atlantic coast, where much of the sustained damage was from storm surge and flooding. For example, the percentage of homes damaged in Pender County, North Carolina, was almost 10 percent.

Some portions of the storm-affected area, such as national forest areas and military installations, are not heavily populated. The one county in Virginia with a damage level above 0.5 percent is in an area where extensive flooding occurred. The overall damage level for all affected counties is slightly less than 1 percent (0.91 percent).

Figure 4-14 Significant damage caused by wind-downed trees.

4.4.2 Mobile Homes

Significant damage to mobile homes at the coast was sporadic. Aerial photographs of the coastal areas show some instances of major structural damage. Figure 4-7 shows an example of sporadic significant damage. The failures normally occurred to the cladding, roof covering, and the structure. When the frame was adequately anchored to the ground, the foundation of the home remained intact and the home's frame remained upright.

Damage to mobile homes in inland areas generally was limited to cladding and roof coverings, as illustrated in Figure 4-16. This home is located a few miles inland of Surf City, North Carolina, and probably experienced sustained winds of less than 90 mph. The sustained wind speed west of Wilmington, North Carolina, was probably less than 70 to 80 mph. At this speed, the wind was able to overturn the unanchored mobile home shown in Figure 4-17. Near Wilson, North Carolina, the wind reached a sustained speed of approximately 50 mph and pulled several sheets of roof sheathing off a mobile home. In addition, there were many instances of trees falling onto mobile homes and causing significant damage.

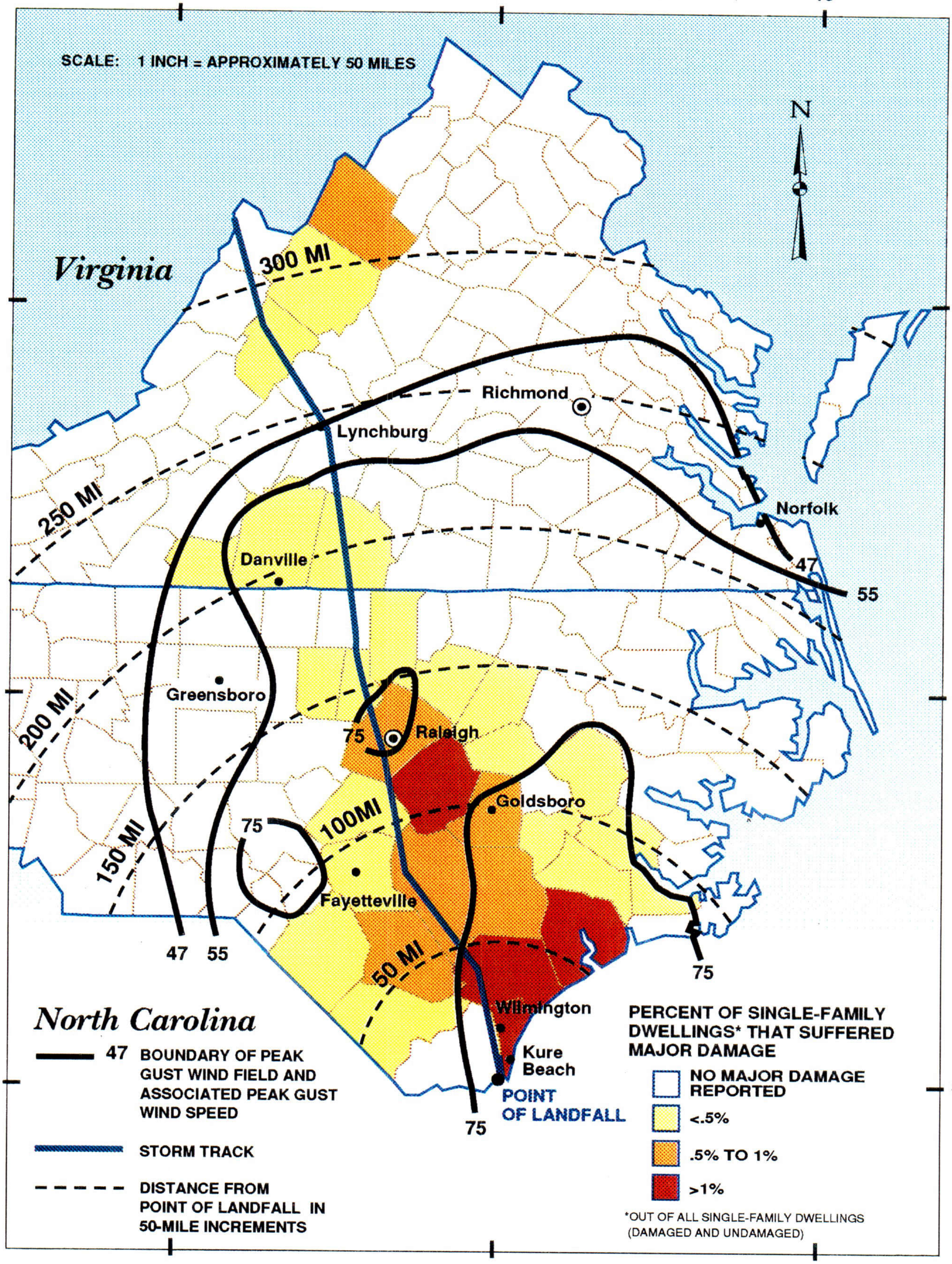


Figure 4-15 Major damage to single-family dwellings.

Figure 4-16 Damage to mobile home cladding and roof coverings.

Figure 4-17 Mobile home overturned by wind.

Figure 4-18 compares the structural damage percentages by county for mobile homes in North Carolina and Virginia with the peak gust wind fields illustrated in Figure 4-2. In seven counties, the damage levels exceeded 1 percent.

The overall damage level is approximately 50 percent higher for mobile homes than for single-family dwellings in the same area.

4.4.3 Apartments

Damage to apartment units occurred primarily along the coast. Figure 4-9 shows examples of wind-related structural damage to roofs along the coast. Additional damage occurred from flooding and storm surge, but the nature of the damage could not be determined from the available Red Cross damage assessment information. In Brunswick County, North Carolina, which was particularly hard-hit, 135 out of 200 units were destroyed or require major repairs.

The damage reported in Rockingham and Rockbridge Counties in Virginia was caused by flooding. Only two units were damaged in Henry County, Virginia, and the cause could not be determined.

Figure 4-19 compares the structural damage percentages by county for apartment units in North Carolina and Virginia with the peak gust wind fields illustrated in Figure 4-2. The overall damage level to apartment units was less than 1 percent (0.72 percent).

4.4.4 Commercial and Public Buildings

Damage to low-rise commercial and public buildings was sporadic and was most evident in the roof and wall cladding systems. Some flat roof coverings were significantly damaged. The amount of damage to roof covering systems was approximately the same 15 miles inland (see Figure 4-20) as it was at the coast (see Figure 4-10). The extent of the damage depended on the type of covering, the age of the covering, and how it was applied/attached to the roof.

There were many single-ply roof membrane failures; however, mechanically fastened single-ply membranes less than 5 years old performed better than those that were more than 5 years old.

The most dramatic roof covering failure was to the Topsail Elementary School, northeast of Wilmington, North Carolina. While 300 people were using the school gymnasium/cafeteria building as a shelter, the standing-seam metal roof peeled back away from the steel bar joist roof system of this 5-year-old facility (see Figure 4-21). The occupants of the shelter had to be evacuated to a building at the adjacent, but older, Topsail High School.

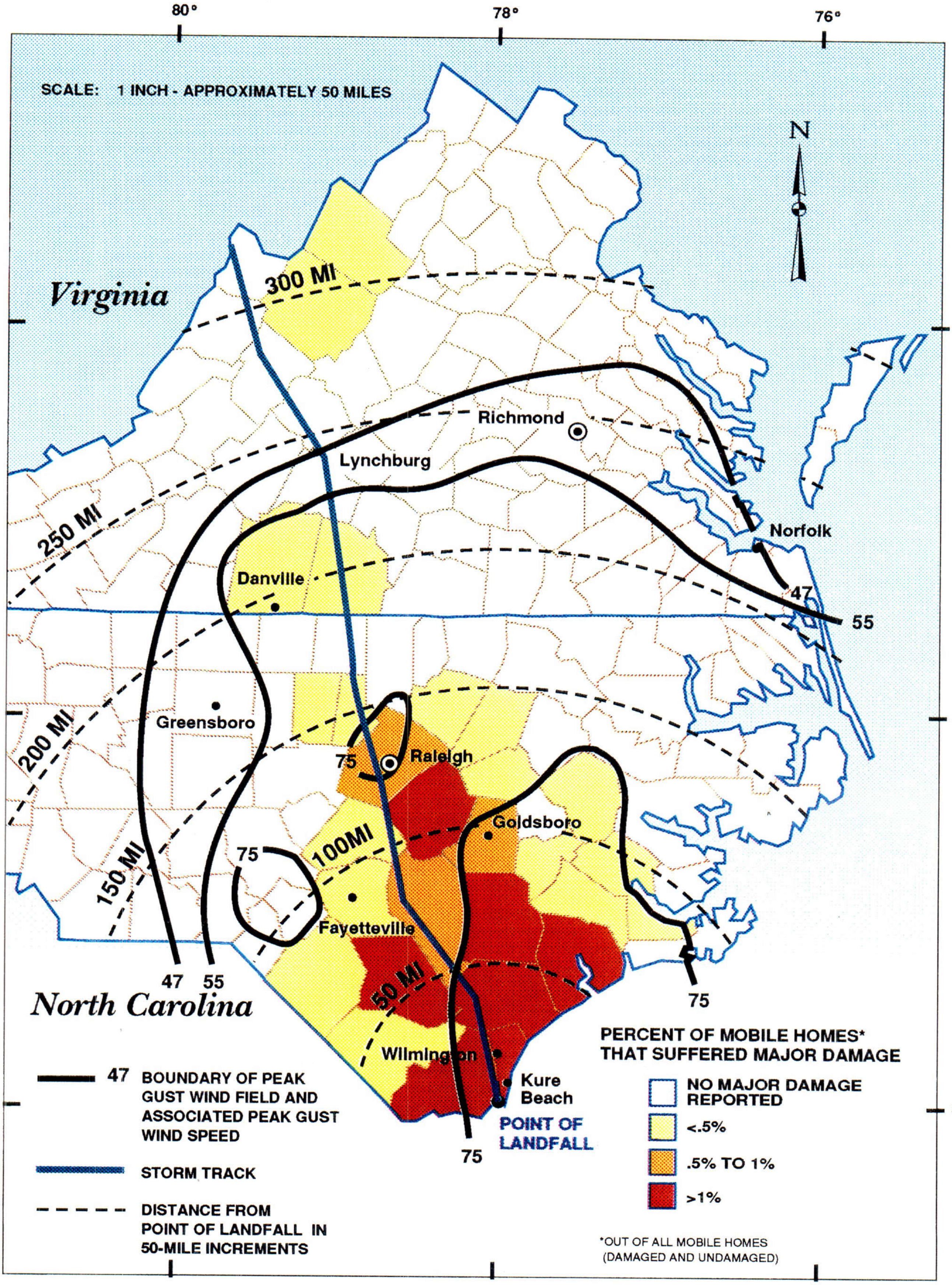


Figure 4-18 Major damage to mobile homes.

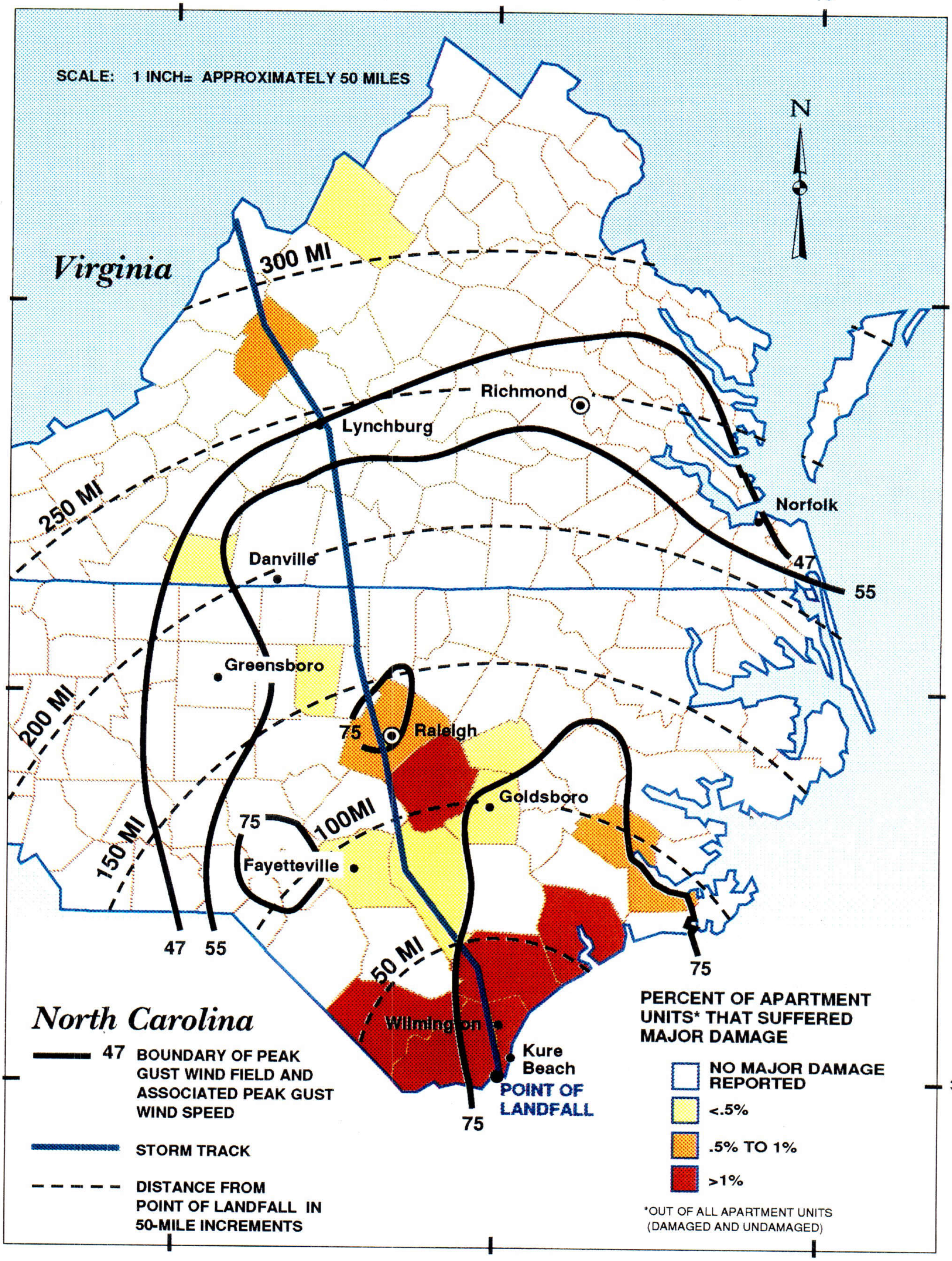


Figure 4-19 Major damage to apartment units.

Figure 4-20 Damage to airport hangar roof at Cherry Point, North Carolina.

Figure 4-21 Standing-seam metal roof peeled back from roof joist system by wind.

In taller buildings near the coast, such as the airport buildings at New River Marine Air Station, cladding failures did occur. Figure 4-22 illustrates the failure of a 4-inch-thick masonry exterior wall that was pulled away from the steel supporting structure. At Cherry Point, standing-seam metal siding was pulled off a hanger building. A single-ply roof membrane failure occurred as far north as Lynchburg, Virginia. This failure appears to be due to a lack of attachment of the membrane to the sheathing, as shown in Figure 4-23.

Figure 4-24 shows an 8-inch-thick masonry wall that was imploded by the wind. The damaged building in this figure, located north of Goldsboro, North Carolina, faced due east, where the terrain was primarily open, and was in an area of significant convective activity where sustained winds reached approximately 70 mph and gusts of almost 90 mph were recorded. It appears the wind pushed on the two garage doors in the front wall of the building until the door jambs began to break the masonry on either side. There is no header across the door opening and no apparent structural center support between the doors. This building was clearly built before the Code went into effect; however it was recently remodeled with a new roof, which was lifted off the building and destroyed.

Figure 4-22 Masonry wall pulled away from steel supporting structure on airport building at New River Marine Air Station, North Carolina.

Figure 4-23 Failure of single-ply roof membrane on building in Lynchburg, Virginia.

Figure 4-24 Masonry wall imploded by wind.

Two structural failures were observed in Wilmington, North Carolina. An airport accessory structure that appeared to be closed on only three sides was destroyed. The roof of a strip mall building was severely damaged when the wind pushed the front facade away from the building and bent a wood support column. The bending of the column allowed the steel roof framing to drop (see Figure 4-25).

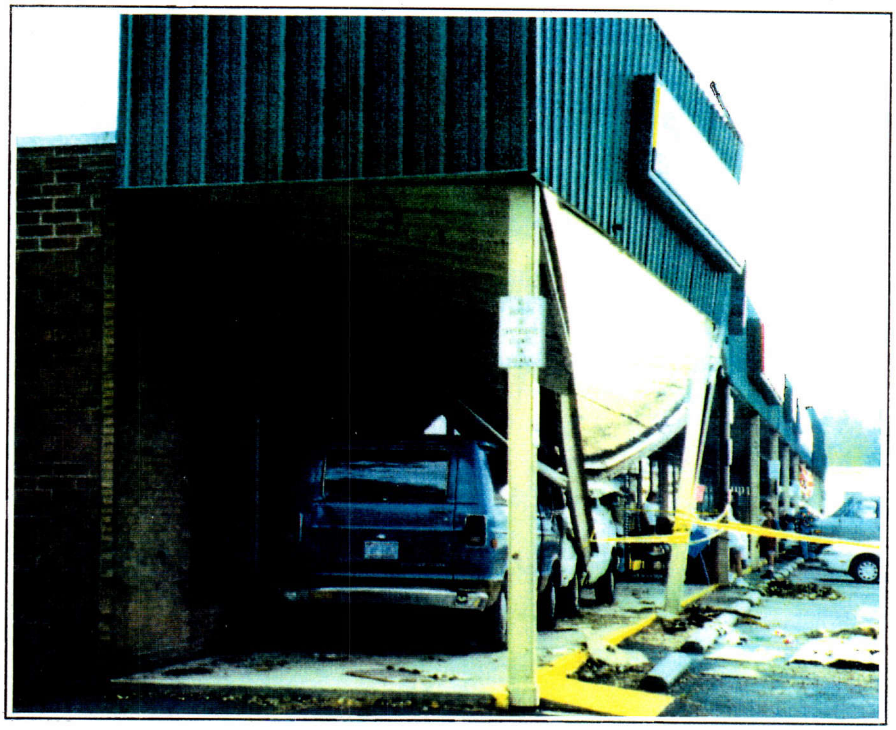


Figure 4-25 Roof damage at strip mall building caused by failure of front facade and support column.

4.5 Crop Damage

The North Carolina State Farm Service Agency Office of the U.S. Department of Agriculture provided information regarding crop losses per affected county. The primary losses were in cotton, corn, soybeans, and timber. In Jones and Wake counties, the losses were primarily in timber, a total loss of approximately 43,000 acres out of almost 600,000 acres.

Crop damage data by county for North Carolina and Virginia are presented in Appendix F. Figure 4-26 compares these data with the peak gust wind fields illustrated in Figure 4-2. Figure 4-27 illustrates the type of damage that occurred to pine trees near Raleigh, North Carolina. The wind that caused the pictured damage had a sustained speed of approximately 50 mph and came from a northeasterly direction.

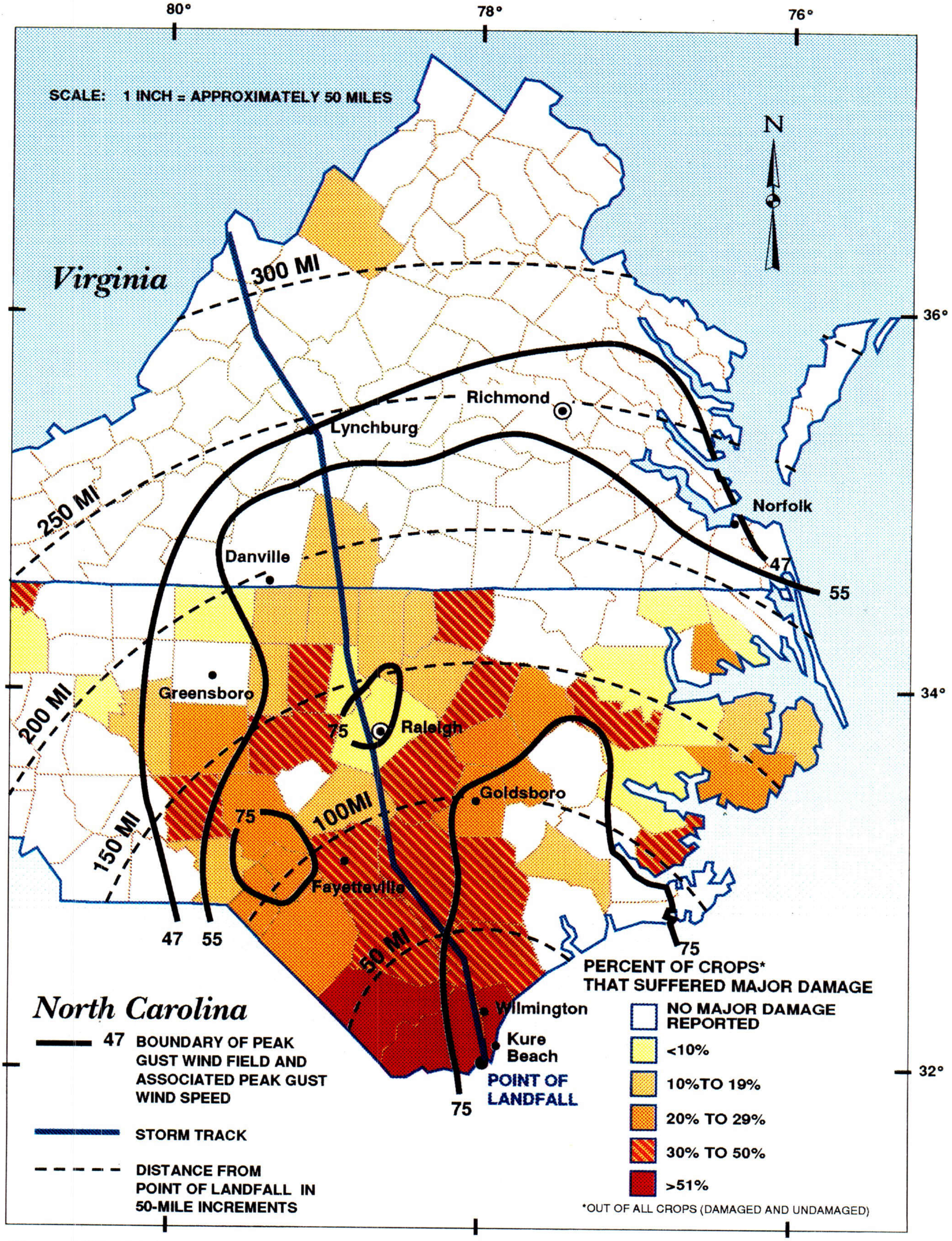


Figure 4-26 Major damage to crops (including timber).

Figure 4-27 Wind damage to pine trees near Raleigh, North Carolina.

There was also loss of livestock (see Figure 4-28), but the data are not normalized and thus are not included in the overall evaluation of storm damage in this report. It is important to note that loss of livestock and other farm animals can occur during a severe wind event.

4.6 Utility System Damage

Damage to utility systems and the resulting power outages were extensive, extending as far north as Washington, DC, and the surrounding counties. At the peak of the power outages, approximately 1,000,000 Carolina Power & Light customers and 300,000 Virginia Power customers were without power.

Damage near the coast included wind-blown power lines, broken poles, and downed trees that fell across power lines. Further inland, the primary damage to the power system was caused by trees falling across power lines.

In densely populated areas like the Raleigh-Durham area, the power outages were almost 100 percent, because of the high population density, the large number of mature trees, and the heavy rains, which softened and loosened the soil around both trees and power poles. The high population density and large

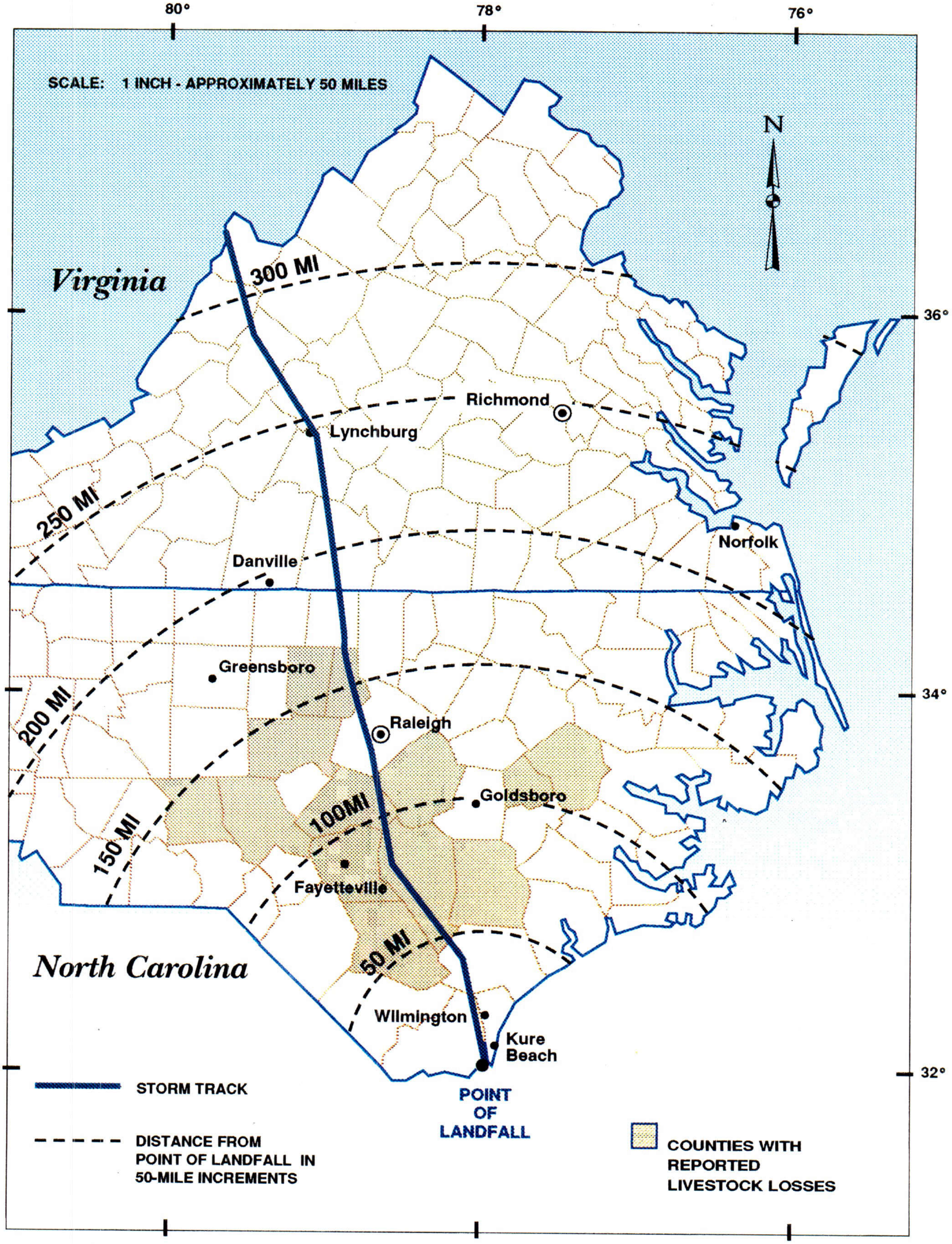


Figure 4-28 Livestock losses.

number of downed trees also increased the time required to bring electric service back to full operation.

Figure 4-29 illustrates a failure mode for power poles that broke at the point where a heavy load (such as a light) was attached. The loss of power affects many types of operations in addition to the residential customer. For example, a liquefied propane gas operator had to shut down his operation and burn off the propane already produced, because electricity is needed continuously to cool the propane and prevent it from creating hazardous conditions in the pipelines. Also, many water and wastewater treatment plants do not have the backup power they need to remain in operation.

Figure 4-29 Failure of power pole at point of load attachment.

Utility outage information was obtained from the utility companies. Many utility distribution systems do not follow county borders, so normalization of the damage information within certain geographical boundaries is somewhat arbitrary. Where the percentage of customers without power was not available, it was estimated: the number of customers without power was divided by 2.7 people per household (meter), and the resulting figure was increased by 15 percent to account for the number of commercial customers.

Figure 4-30 compares power outages, in maximum percent of customers without power, by county in North Carolina and Virginia with the peak gust wind fields illustrated in Figure 4-2. The area to the right of the storm track clearly had more customers without power than did the area to the left. It should be noted that because of the geographic distribution of power service areas, the number of customers affected by power outages probably included some who were not in the swath of the storm.

4.7 Rain Effects

Hurricane Fran produced record rainfall totals from the coast to Raleigh, North Carolina. Rainfall intensity was high both along and to the right of the storm track. The intense rain created flash floods in the Raleigh-Durham area that washed out roads, bridges, and dams. The storm created many other flash floods in the Virginia and West Virginia mountains. Wintergreen, Virginia, received 10.72 inches of rain. The flooding caused the Potomac River to crest 18 feet above flood stage at Harper's Ferry, West Virginia. The 100-year flood levels were exceeded in many communities. Figure 4-31 shows the rainfall totals along the storm-affected area.

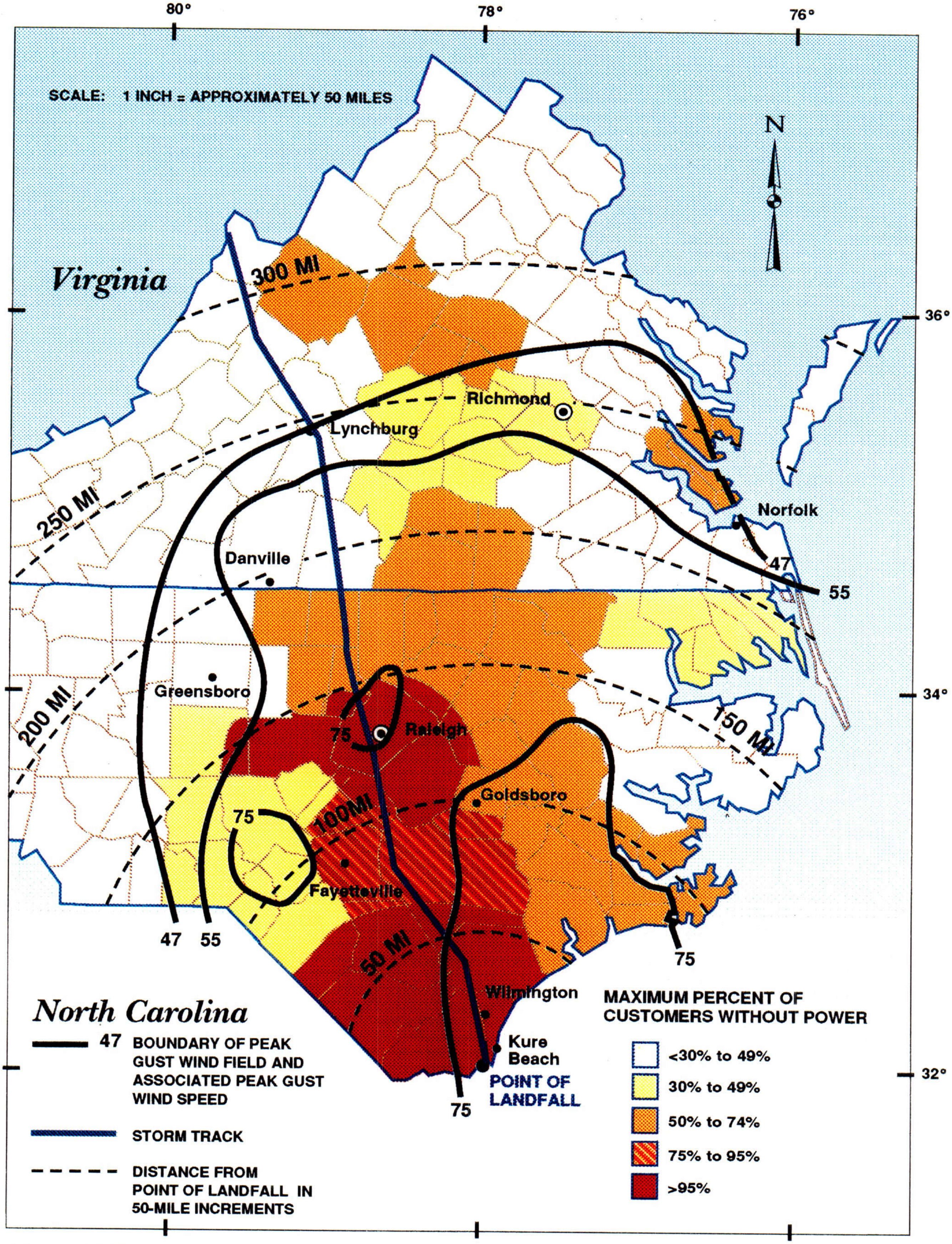


Figure 4-30 Power outages.

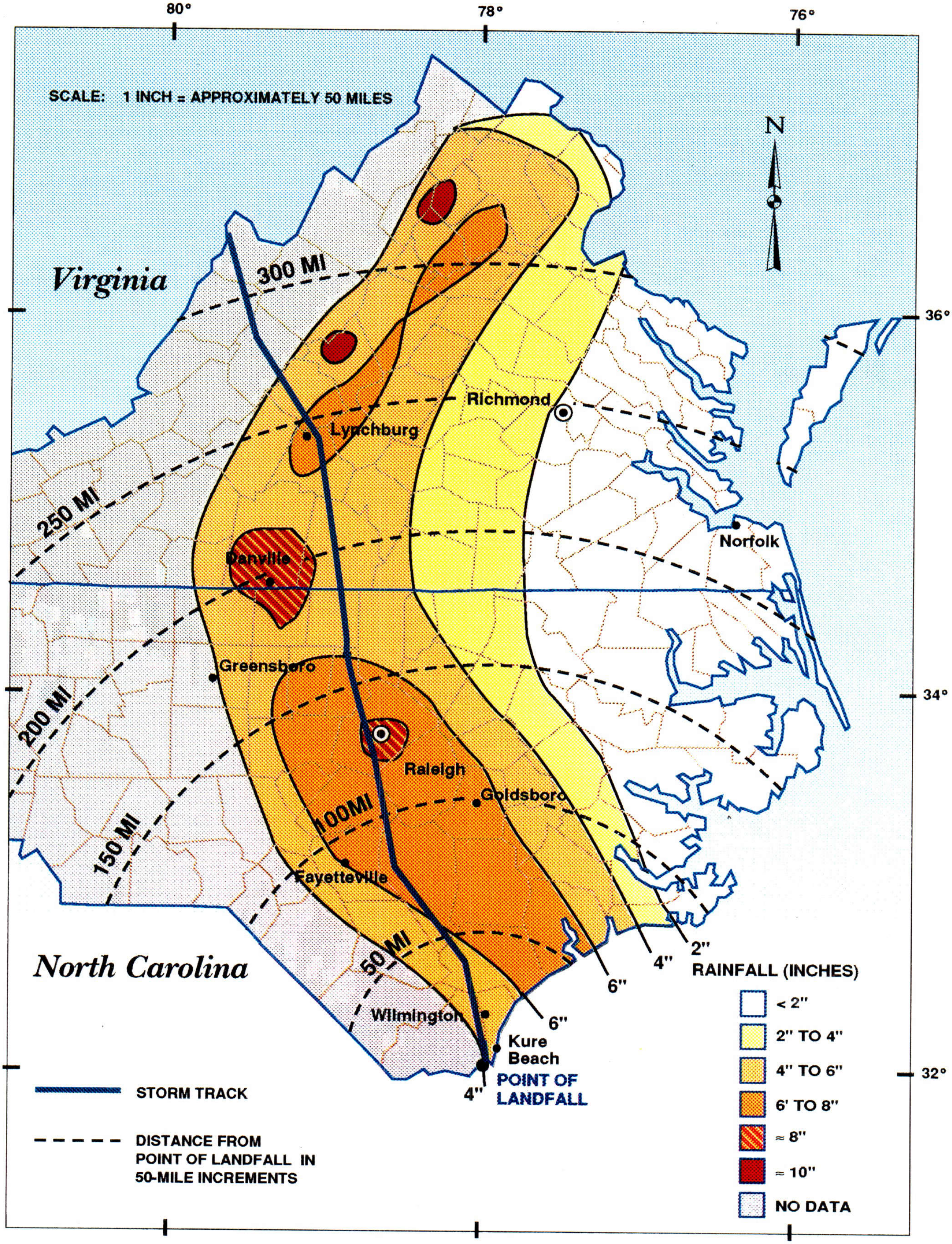


Figure 4-31 Rainfall.

5 INLAND WIND COMPARISONS FOR HURRICANE FRAN

5.1 FEMA Inland Wind Model

The Inland Wind Model, Version 1.0 for use with a PC, was developed to provide emergency managers with a predictive tool that would help them in their decision making processes regarding the preparedness and awareness of the population of storm-threatened inland areas. The model graphically displays in color the inland wind swath for a storm, the storm track, and the area predicted to experience maximum sustained wind speeds greater than 40 mph, greater than 58 mph, and greater than 75 mph (hurricane-force winds).

The model is intended to be used only in the last hours of a landfalling hurricane, when the forecast errors are relatively low. The input to the model is the NHC's Tropical Cyclone Forecast/Advisory, which provides the storm's location in latitude and longitude; the radius of sustained winds at 34 knots (39 mph), 50 knots (58 mph), and 64 knots (74 mph); and the 12-, 24-, 36-, 48-, and 72-hour forecast positions for the storm. The forward speed at landfall and the direction of the storm are crucial to the decision-making process for local emergency managers. The program is available to most emergency managers in hurricane-threatened areas and enables them to display forecast inland wind swaths quickly, to consider many possible scenarios, and to develop "what if" decision trees.

5.2 Hurricane Fran Predictions Based on the FEMA Inland Wind Model

The program option for the maximum envelope of winds (MEOW) is the Inland Wind Model tool that approximates the general storm decay rates developed by the NHC. The wind swath shows a specific storm track and the wind speed coverage area. The MEOWs are taken directly from maps provided by Drs. Kaplan and DeMaria of the HRD in connection with their published documentation of the Decay Model in the *Journal of Applied Meteorology*, January 1995.

The input options for the MEOW are limited. When a landfalling sustained wind speed of 121 mph and a forward speed of 14 mph is selected (which is the closest input option to the NHC-predicted speed of 115 mph), the model shows that 92-mph or greater wind speeds would travel inland 30 to 35 miles, hurricane-force winds of greater than 75 mph would extend inland approximately 85 miles to Fayetteville, North Carolina, and storm-force winds would be felt in South Boston, Virginia, approximately 180 miles inland.

Figure 5-1 shows the wind swath displayed by the Inland Wind Model for Hurricane Fran at the time of tropical forecast advisory no. 49, the last advisory prior to landfall. In Figure 5-2, the wind swath shown in Figure 5-1 is overlaid on the MEOWs for a storm with a landfalling wind speed of 121 mph and a forward speed of 14 mph. A review of Figure 5-2 reveals that the model (based on a 121-mph sustained wind speed and a forward speed of 14 mph) displayed predicted sustained wind speeds across the spectrum of wind fields except at the cost for the 92-mph wind field. In all other wind fields, there is at least one recorded sustained wind speed that is inside each of the model's wind fields as defined by the overlay of the wind swath on the MEOW.

The Model wind swath display for tropical forecast advisory no. 49 indicates that hurricane-force winds would extend past Raleigh, or some 120 miles inland. The wind swath is large because the tropical forecast advisory does not indicate when 35-knot, 50-knot, or 75-knot winds end between 12-hour forecast points -- just that they exist at one point and not at the next. Therefore, without additional guidance from the NHC, it becomes necessary to taper such winds to zero at the first point at which zero range of such winds is encountered. The wind swath has been estimated for the affected areas of Virginia because the Inland Wind Model currently has no data for any areas north of North Carolina.

An evaluation of the Inland Wind Model using the MEOWs is limited in that a storm scenario cannot be created with a landfalling wind speed and forward speed that equal the actual conditions. Because only a set range of speeds can be input to the MEOW portion of the Model, the storm conditions can only be approximated.

When the evaluation of the Inland Wind Model is based on a landfalling speed of 98 mph (shown in Figure 5-3), which is closer to the actual sustained speed at landfall of 90 to 100 mph, all of the model's wind fields have a recorded sustained wind speed that falls within the defined field. Figure 5-4 shows the peak gusts compared to the wind fields of a 98-mph landfalling storm.

The graphical comparisons shown in Figures 5-2 and 5-3 are summarized in Tables 5.1 and 5.2 and are shown in detail in Appendix G. The average sustained wind speeds of all of the recording stations within each wind field are compared to the lowest wind speed in each field, since the Inland Wind Model is considered accurate if any recording station in a defined wind field experiences the wind speed displayed for that field.

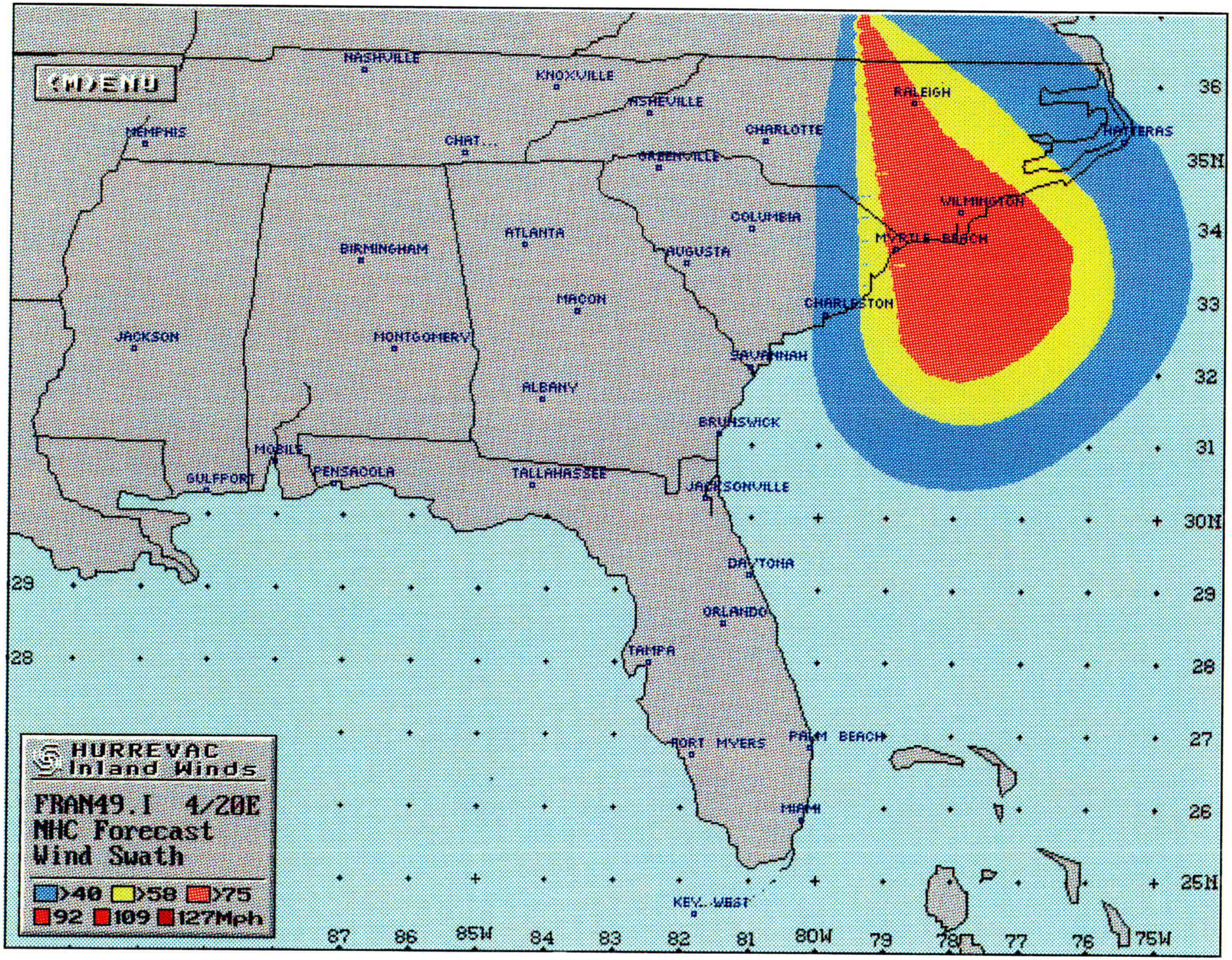


Figure 5-1 Wind swath for Hurricane Fran at tropical forecast advisory no. 49.

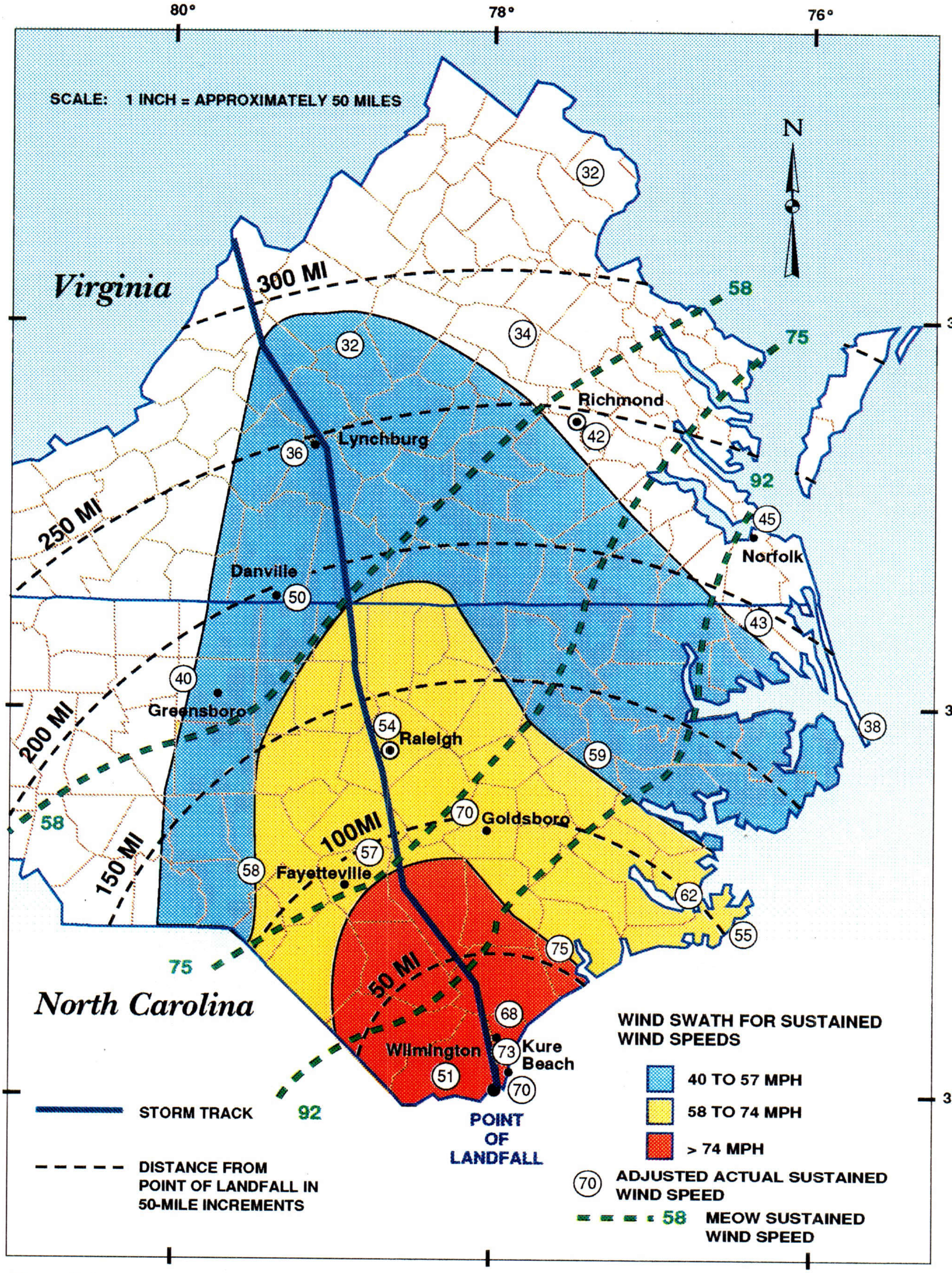


Figure 5-2 Hurricane Fran at tropical forecast advisory no. 49. MEOW and wind swath for sustained wind speeds based on a sustained wind speed of 121 mph at landfall and a forward speed of 14 mph.

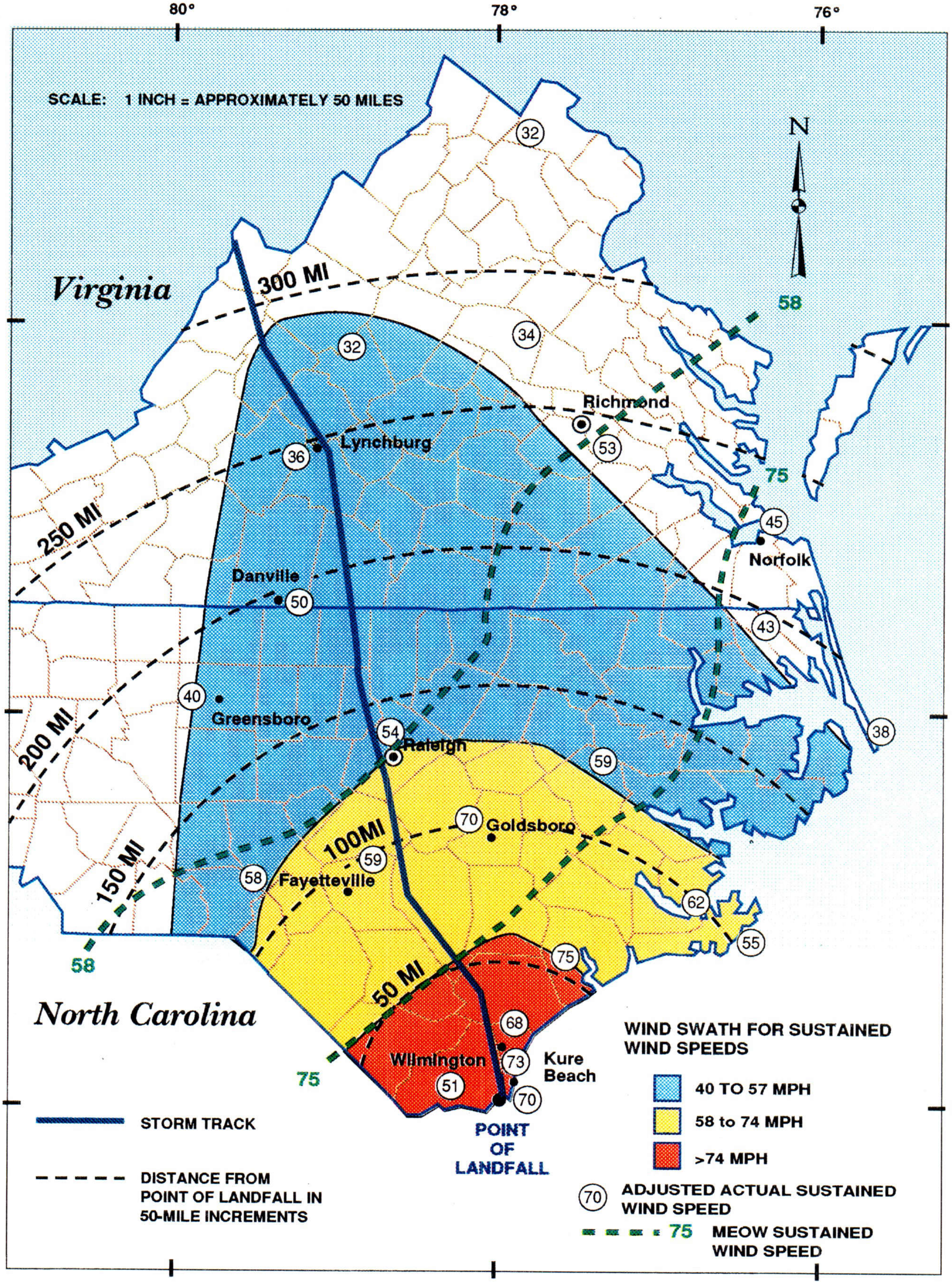


Figure 5-3 Hurricane Fran at tropical forecast advisory no. 49. MEOW and wind swath for sustained wind speeds based on a sustained wind speed of 98 mph at landfall and a forward speed of 14 mph.

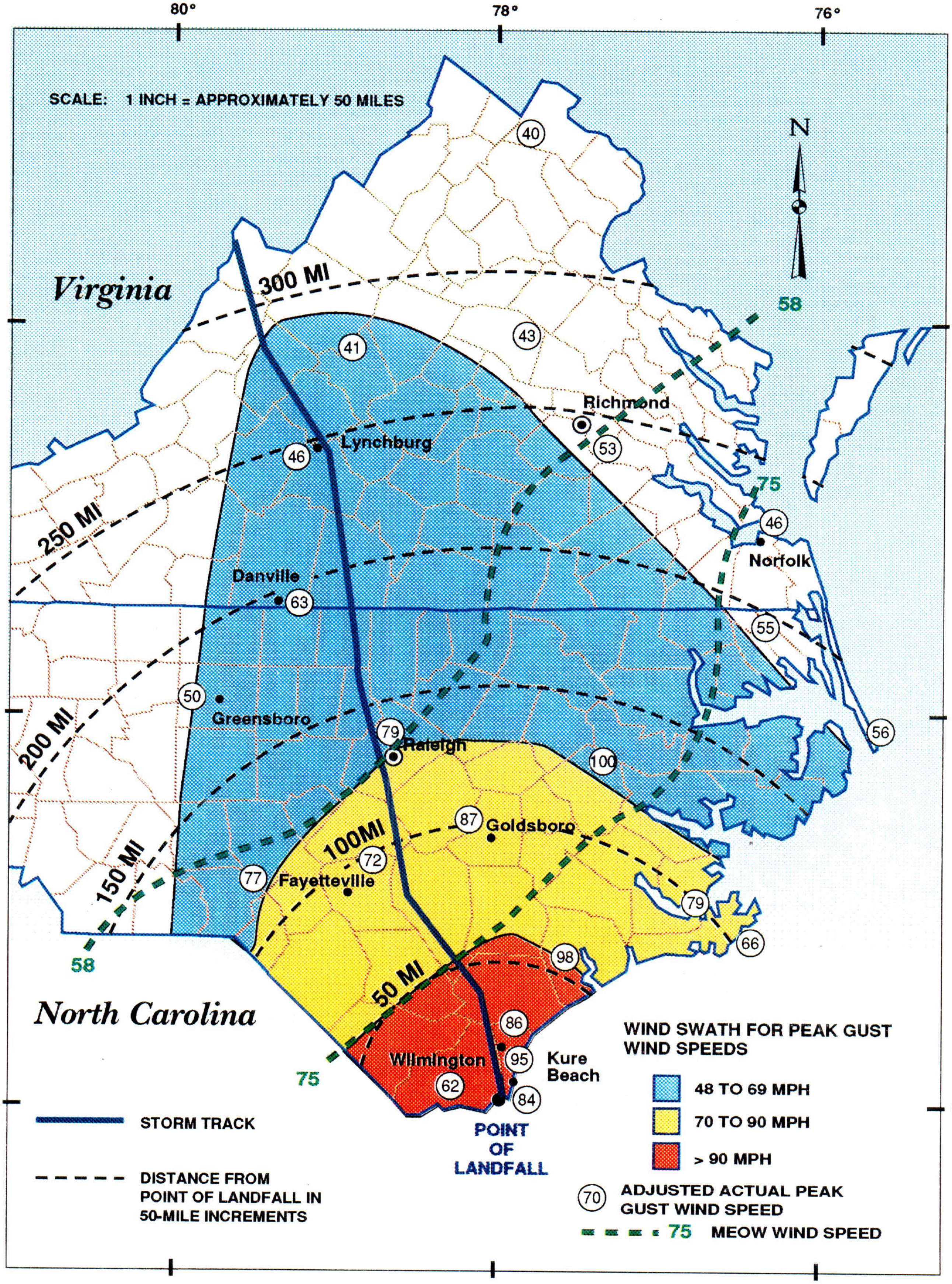


Figure 5-4 Hurricane Fran at tropical forecast advisory no. 49. MEOW and wind swath for peak gust wind speeds based on a sustained wind speed of 98 mph at landfall and a forward speed of 14 mph.

Table 5.1 Comparison of MEOWs to Adjusted Recorded Sustained Wind Speeds at a 121-mph Landfall Speed

RANGE OF MEOW SPEED (mph)	AVERAGE SUSTAINED SPEED	PERCENT DIFFERENCE
92 - 108	67	+ 27.2
58 - 74	59	- 1.7
40 - 57	40	0

Table 5.2 Comparison of MEOWs to Adjusted Recorded Sustained Wind Speeds at a 98-mph Landfall Speed

RANGE OF MEOW SPEED (mph)	AVERAGE SUSTAINED SPEED	PERCENT DIFFERENCE
75 - 92	67	+ 10.7
58 - 74	59	-1.7
40 - 57	40	0

5.3 Inland Wind Model Critique

The Inland Wind Model has the potential for providing valuable wind speed forecasts to inland areas. As noted previously, because the model's starting point is the NHC tropical cyclone forecast, improvement of the landfalling forecast will improve the model's accuracy.

The Inland Wind Model seems to fairly represent the overall shape of the inland wind fields as a large "teardrop." The overall wind pattern is also accurately depicted as being stronger on the right side of the storm track. In the inland wind studies conducted for both Hurricane Opal and Hurricane Fran, wind fields have been noticeably stronger on the right side of the storm track and substantially diminished on the left side. The 12-hour difference in forecast position creates an unrealistically large wind swath. A shorter time between inland forecast points would reduce the predicted distance inland that high winds are expected to extend.

The map legend used for the wind forecast maps shown in Figures 5-1 through 5-4 includes six colors that represent six wind speeds (in mph): >40, >58, >75, 92, 109, and 127. However, the displayed wind swath is shown with only three colors, those for >40 mph, >58 mph, and >75 mph. These three wind speed categories are the only categories provided by the NHC in their storm forecast. The user is therefore led to conclude that winds of 92 mph and above did not occur. Also, the colors that represent the four highest wind speeds are so similar to one another that even if they were all displayed, there would still be confusion.

The Inland Wind Model, including the MEOW options, is being expanded to cover the northeast (from North Carolina to Maine). This program addition will be operational in late 1997.

6 CONCLUSIONS

6.1 Accuracy of the Inland Wind Model

As discussed in Section 5.2, the accuracy of the Inland Wind Model is a direct function of the accuracy of the NHC tropical forecast advisory. The appropriate surface wind and forward speed of the storm at landfall are the most important input to the model. The decay rate of the storm seems to be approximately correct as evidenced by Figures 5-2 through 5-4.

6.2 Damage Predictions

The DRG shown in Table 4.2 is based on the Beaufort Scale used by the NWS to estimate sustained wind speeds. The expected damages described in Table 4.2 are based on the Beaufort Scale, the Saffir-Simpson Scale corrected to the form originally intended by Saffir, and observations of the effects of Hurricanes Frederic, Hugo, Andrew, Opal, and Fran.

From the observed and reported damage, we conclude that the adjusted wind speeds for Hurricane Fran, shown in Table 4.1, are approximately correct. The following examples of damages caused by Fran illustrate the use of the DRG.

- In areas of 55- to 75-mph peak gusts, extensive tree damage and tree uprooting occurred. This damage caused significant collateral damage to structures and the power distribution system. Power outages were on the order of 50 to 74 percent.

- In areas of greater than 75-mph peak gusts, the power outages were nearly 100 percent. These areas were primarily within 50 miles of the point of landfall of the storm.

- The incidences of severe damage to manufactured homes occurred in the areas of hurricane-force winds. One unanchored manufactured home was overturned where peak gusts were less than 95 mph.

- Damage to roofs by wind occurred primarily near the coast where the peak gusts were approximately 95 to 100 mph. Significant damage to some flat roofs at the coastline indicates the existence of some pockets of 110- to 120-mph peak gusts.

- Extensive roof damage and some failures in building envelopes indicate that some areas experienced Category 2 strong hurricane-force winds of 96 to 110 mph.

6.3 Damage/Distance Inland Relationship

One of the important relationships to consider is the degree and type of damage that occurs as a function of the distance from the storm's point of landfall.

There does not appear to be any difference in the type or amount of damage inland when the area is struck by hurricane-force winds than there is at the coast except as the following apply to the situation:

1. Winds at the coast bring salt-laden air and will therefore kill more vegetation and create more long-term corrosion than wind moving at the same speed in inland areas. There is no factual data available on how far inland salt laden air will travel, but certainly the salt concentrations will decrease with distance.

2. Terrain effects may cause damage patterns inland that are different from those observed at the coast. These effects include the channeling of air around buildings or large tree- or vegetation-covered areas.

3. In inland areas, the wind patterns will be more broken. Also, severe wind is likely to be more localized in inland areas than at the coast because of the difference in surface features and because the storm will likely be breaking apart at some distance inland. This distance will always vary with the intensity and forward speed of the storm.

As discussed earlier, it is apparent from this investigation and from the study of Hurricane Opal inland winds that more damage is occurring on the right side of the storm track as the storm advances inland. One of the significant inland effects of hurricanes is intense rain, whose effects will vary according to how saturated the ground is and how full the runoff channels are from previous rainfalls. However, an intense rainfall can create severe flooding conditions, including flash floods, which pose significant risks to lives and property.

6.4 Summary

From our analysis of Hurricane Fran inland winds, we have drawn the following conclusions:

1. The MEOW portion of the Inland Wind Model is a good representation of the hurricane's decay rate. When the wind swath portion of the display is overlaid on the MEOW, it is a good representation of the storm-related wind fields. The most accurate MEOW scenario for Hurricane Fran is a storm with a landfalling wind speed of 98 mph and a forward speed of 14 mph.

2. The MEOW predicts wind speeds that are closer to the actual adjusted peak gust wind speeds than to the sustained wind speeds.

3. The damage caused by Hurricane Fran is representative of the damage predicted by the DRG.

4. More damage occurs on the right side of the storm track. Heavy rains also occurred on this side of Fran and caused severe flooding.

5. There is no apparent difference in damage levels from similar wind speeds at different distances from the coast except that caused by the effect on wind of terrain or objects that create surface friction.

6. The Inland Wind Model can be successfully used as a tool to help predict the effects of inland winds on communities. The more improved the tropical forecast, the more improved the Inland Wind Model will be, since the model's accuracy depends on this forecast.

7. Comparing the model output with the effects from several more storms will provide a basis for improving the accuracy of the model.

7 RECOMMENDATIONS

7.1 Wind Speeds

From the comparison of results of the Inland Wind Model and experience, and considering that most wind damage is caused by gusts, it is recommended that research be conducted to determine how predictions of wind effects could be based on peak gusts, not sustained winds. The purpose of this research is to develop a relationship between peak gusts and 1-minute sustained winds. Much of the data collected from this storm are in the form of peak gusts because the measurement of sustained winds is not at all consistent across the various types of reporting mediums and methods. The decay rate used in the Inland Wind Model seems to be approximately accurate and is approximately the same as that provided by the NHC model.

As stated in *Study of Inland Wind Effects of Hurricane Opal*, additional wind fields above 75 mph should be added to the Inland Wind Model because significant damage doesn't normally occur until wind speeds reach 95+ mph, a wind speed equivalent to that of a strong hurricane. This change would require that the same information be added to the NHC forecasts.

7.2 Mitigation Measures

The following sections present mitigation measures by categories of the most likely failure modes:

- Structural failure from excessive wind force
- Building envelope failure from both wind and windborne debris
- Penetration of the building envelope by windborne debris
- Support services (power, water, waste disposal) severed and infrastructure affected

7.2.1 Structural Failure -- Excessive Wind Force

> A mitigation measure that will help prevent failure of the structural system of any building is conformance with current building codes and practices.

The pertinent codes in place in the area of the country impacted by Hurricane Fran are the North Carolina State Building Code and the ASCE Design document *Minimum Design Loads for Buildings and Other Structures* also known as ASCE 7-95.

There appeared to be much evidence that buildings perform better during severe wind events when building codes that deal adequately with the expected storm-related forces are in place and enforced. The evidence from this event is in the performance of foundation systems that withstood high storm surge and in the performance of the structural systems, including the roofs that withstood the 90- to 100-mph wind speeds.

It should be noted that the recorded speeds shown for the 3-second peak gust on the wind map in ASCE 7-95 were not exceeded anywhere during Hurricane Fran. See Figure 4-4 for the portion of the ASCE wind map that pertains to the area affected by Fran.

One important mitigation measure is to treat carports, canopies, porches, overhangs, and similar appurtenances as structures. If they were always treated as structures, they would be designed to resist the significant uplift they experience when high winds get under them. If this effect is not considered, the wind can rip them away from the main structure, possibly damaging the roof and creating debris. Therefore, these appurtenances must be adequately secured to the structure and anchored to prevent uplift. An alternative mitigation measure is to enclose them to prevent the wind from entering and causing uplift.

An important mitigation measure for manufactured homes is to install them on permanent foundations that are anchored securely to prevent the homes from overturning or sliding off their foundations when acted on by wind pressure. Once a manufactured home loses attachment to its foundation, it becomes a windborne missile and may cause damage to other structures. An unsecured manufactured home can be overturned by a wind gust speed of approximately 80-95 mph.

7.2.2 Building Envelope Failure

The building envelope is defined as the part of a structure that keeps out the elements and therefore includes the roof, windows, doors, and exterior siding. In most residential structures, the primary concern is keeping the roof on and the windows and doors intact. The primary mitigation measures are therefore to protect (cover) the windows and doors and to install or retrofit the roof so that it does not fail under the design wind conditions.

Windborne debris begins to be created at wind gusts of approximately 80 mph (storm-force winds). A mitigation measure known to be successful is to protect the windows and doors from breaking and thereby prevent the wind from entering the structure and creating more damage.

While there is not considerable evidence of damage to inland structures by windborne debris, it is suggested that the recommendation be made that building owners cover the openings in their buildings when wind gusts are expected to exceed 80 mph.

The vulnerability of a building envelope to damage from windborne debris is a function of the building location and the type of "debris" near the building. A building with a large storefront window could be expected to suffer some debris damage if the building is near a gravel-covered parking lot or road or is adjacent to unsecured debris such as trash cans.

Once the building envelope is penetrated, failures can occur when the wind enters the building and adds outward pressure to the walls and roof and when rain causes extensive water damage to building materials not designed to be wet. When materials such as insulation are saturated by water their dead weight increases significantly, further increasing the risk of failure.

Roof covering failures begin to occur at wind gusts of approximately 80 mph, although shingles and other coverings can come loose in 70-mph winds.

These failures can be prevented if new roofs are designed to resist the loads specified in the appropriate building code documents and engineering standards, including ASCE 7-95. If roofs were designed and installed to these standards, the expected wind events would not do serious damage to them. Because a significant increase in suction pressure occurs at the edges of the roof surface, additional care in the installation of roof materials in these critical areas would reduce damage.

As evidenced by this event, there are still some types of roof coverings whose installation requires special care in high-wind areas. Single-ply membrane roofs failed in Cherry Point, North Carolina, on an airport building that experienced approximately 76-mph peak gust wind speeds. The failure occurred in the attachment of the membrane to the roof deck and in the edge flashing. A single-ply membrane roof failed at the Lynchburg, Virginia, airport where peak wind gusts did not reach 50 mph. This failure also occurred in the attachment of the membrane to the roof deck.

A standing-seam metal roof failed on an elementary school building used as a shelter north of Wilmington, North Carolina, where the peak gust wind speed does not appear to have exceeded 90 to 95 mph. Three hundred people were in this 5-year-old school gymnasium at the time the roof failed.

7.2.3 Missiles

The concept of eliminating missiles is very important whenever wind gusts are expected to exceed 65 mph. At this speed the wind will begin to blow small, loose objects about, potentially creating missiles that will break the glass in a window or door and allow wind and rain to penetrate the building envelope.

When wind gusts reach approximately 75 mph, small stones can become airborne and add to the missile hazard because of their greater weight and greater potential for causing damage. Before a significant wind event occurs, owners should be encouraged to tie down or put away items on their property that could blow around and cause damage. Such items would include trash cans, lawn chairs, small toys, landscaping decorations, loose branches, flags, and debris.

At higher wind speeds, larger objects such as stones and tree limbs become more dangerous missiles. Stone is frequently used as ballast for flat roof systems such as built-up asphalt and single-ply membranes. High winds can scour the roof, picking up stone. Roof stone missiles can be eliminated if the ballast is replaced with pavers, particularly around the roof edges, which are most vulnerable to scour and uplift. Alternatively, larger stone in greater quantities could be used to increase the weight on the roof and make scour by wind less likely, or parapets could be added or increased in height to reduce scour.

Trees growing near buildings are a frequent source of damage. Mitigation measures include pruning trees back so that no branches overhang any portion of the roof; removing diseased trees, damaged trees, and trees that have split trunks; and planting trees no closer to a building than the expected height of the full-grown tree.

7.2.4 Support Services

The primary failures in support services occur because of damage to the power distribution system. Power failures affect other community services, such as water distribution, wastewater treatment, shelters, and critical care facilities.

Assuming that power failures are inevitable, plans must be developed for providing continued service to the community. Critical care facilities and shelters must therefore have independent emergency power systems that are fully operational when needed, and they must have plans for periodic testing of those systems. Critical care facilities must also have plans in place for dealing with the loss of municipal water and wastewater treatment.

Community-wide service providers such as water and wastewater treatment facilities must decide with the help of the community how and at what level service will be maintained when the power goes out.

Major power interruptions can be expected when wind gusts reach approximately 70 mph.

Mitigation measures available to reduce power distribution loss are limited to placing the power system underground, installing poles designed and embedded to withstand wind gusts, and expanding the clear area around transmission lines, poles, and transformers. This clear area can be increased by trimming back trees so that the distance from the tree line to the power system is at least equal to the expected height of the trees. Where this distance cannot be achieved, a tree trimming schedule should be initiated to maintain as much space between the trees and power system as rights-of-way allow. If new trees are to be planted, deep-rooted types should be considered because they will survive high winds better than shallow-rooted trees. Shallow-rooted trees begin to be uprooted and cause major damage when sustained wind speeds reach approximately 60 mph.

There was some evidence from this storm of power poles snapping at the point where heavy loads such as transformers and lights were supported. In high winds, the poles behave like a cantilever beam, secured in the ground but attempting to support the weight of the transformer or light in addition to the force of the wind. The wood poles appeared not to have been designed for this excessive force.

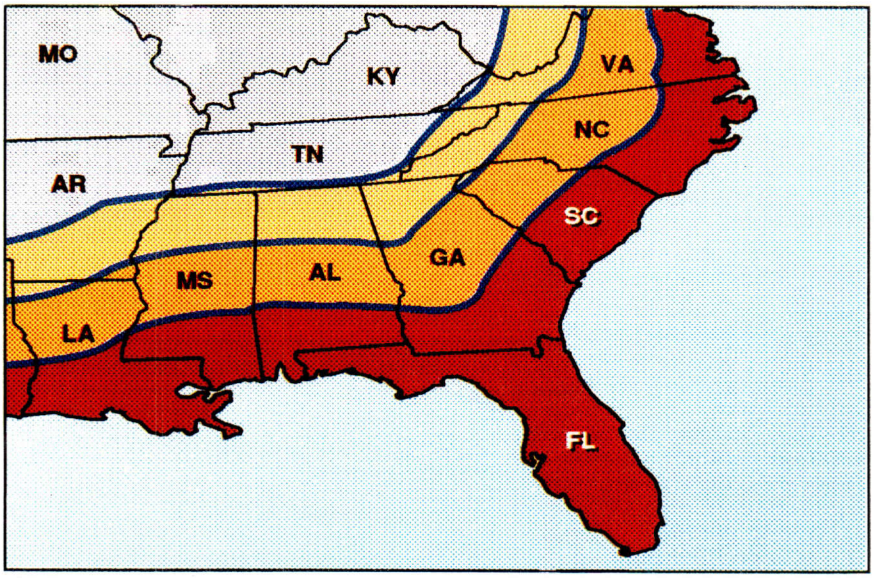
Relocating the transformer or light to a different support or reinforcing the pole may be two ways to reduce damage to poles.

7.2.5 Summary

The table in Figure 7-1 summarizes the mitigation measures discussed above. For four wind speed ranges, it lists the types of damage most likely to occur and the mitigation measure(s) that will reduce the damage. The measures are intended to be applied cumulatively as the expected wind speed increases. The map in Figure 7-1 shows the inland extent of the expected sustained wind speeds listed in the table for a wind event with a recurrence interval of approximately 50 years. The wind fields shown on the map are based on the Inland Wind Model MEOW for a hurricane with a sustained wind speed of 144 mph and a forward speed of 25 mph at landfall.

EXPECTED SUSTAINED WIND (MPH)	EXPECTED PEAK GUST (MPH)	MITIGATION MEASURES
55-63 STORM FORCE	*71-80*	• Secure loose objects. • Cut trees back away from buildings and power lines. • Install properly embedded power poles. • Plant new trees a distance from building equal to height of full grown tree. • Provide and test generator back-up power. • Install roofing materials according to design specifications, particularly at edges.
64-74 STORM FORCE	*81-95*	• Cover windows and doors. • Add pavers or ballast to flat roofs. • Mechanically fasten single-ply roof membranes and eliminate ballast. • Reinforce power poles used for equipment support. • Protect critical care facilities and shelters and make them self sufficient.
75-94 HURRICANE FORCE	*96-125*	• Install roof coverings according to design specifications for high wind areas. • Design Structural roof framing for high-wind areas. • Design structural building attachments, e.g., porches, canopies, overhangs, signs, for high-wind areas. • Anchor manufactured homes to prevent overturning.
>95 GREATER HURRICANE FORCE	*>126*	• Design all structural connections, building attachments, and building envelop protection for hurricane-force winds.

Insufficient data



NOTE:

Map based on Inland Wind Model MEOW for Category 4 Hurricane with a sustained wind speed of 144 mph and a forward speed of 25 mph at landfall (50-year recurrence interval).

Figure 7-1 Sustained wind speeds and associated mitigation measures.

7.3 Future Storms

The quality of the information derived from this model will be significantly improved with the evaluation of more storm data. Such data can be gathered for future landfalling hurricanes and other high-wind events in practically "real time" with the use of the Internet, computers, and a pre-storm workplan. It is recommended that continuing storm evaluation services be provided for the foreseeable future. The required work would include collecting and analyzing storm, wind, and damage information for every hurricane that makes landfall, no matter what category. The goal would be to enhance the quality and quantity of information provided to emergency managers and the timeliness of the delivery of that information.

The quality of the information used in the evaluation of storms depends entirely on the quality of the wind measurements, which is seriously jeopardized when wind recording instruments are not provided with backup power. Sufficient evidence is available to predict that power is likely to be lost at wind speeds of 60 to 70 mph. Therefore, any recording station will probably be rendered useless during hurricane-force winds. It is recommended that NOAA and the NWS work diligently toward providing backup power to all weather recording stations. The relationship between barometric pressure and wind speeds should be compared for the next several inland storms to provide another tool for assessing inland wind effects.

Recent NWS policy statements suggest that NWS measurement instruments should be taken down when severe storms are approaching so that the instruments are protected from damage. However, these instruments provide valuable research data for life safety mitigation planning and engineering purposes, and it is strongly recommended that these instruments remain in place during all high-wind events.

APPENDIX A

Map of Deaths Caused by Hurricane Fran

Appendix A

Map of Deaths Caused by Hurricane Fran

The map on the following page shows the locations, numbers, and causes of deaths that resulted from Hurricane Fran. Also shown is the storm track, from the point of landfall to the southwest corner of Pennsylvania. This map was provided by the National Oceanic and Atmospheric Administration, National Hurricane Center. The key to the letter designations shown on the map is as follows:

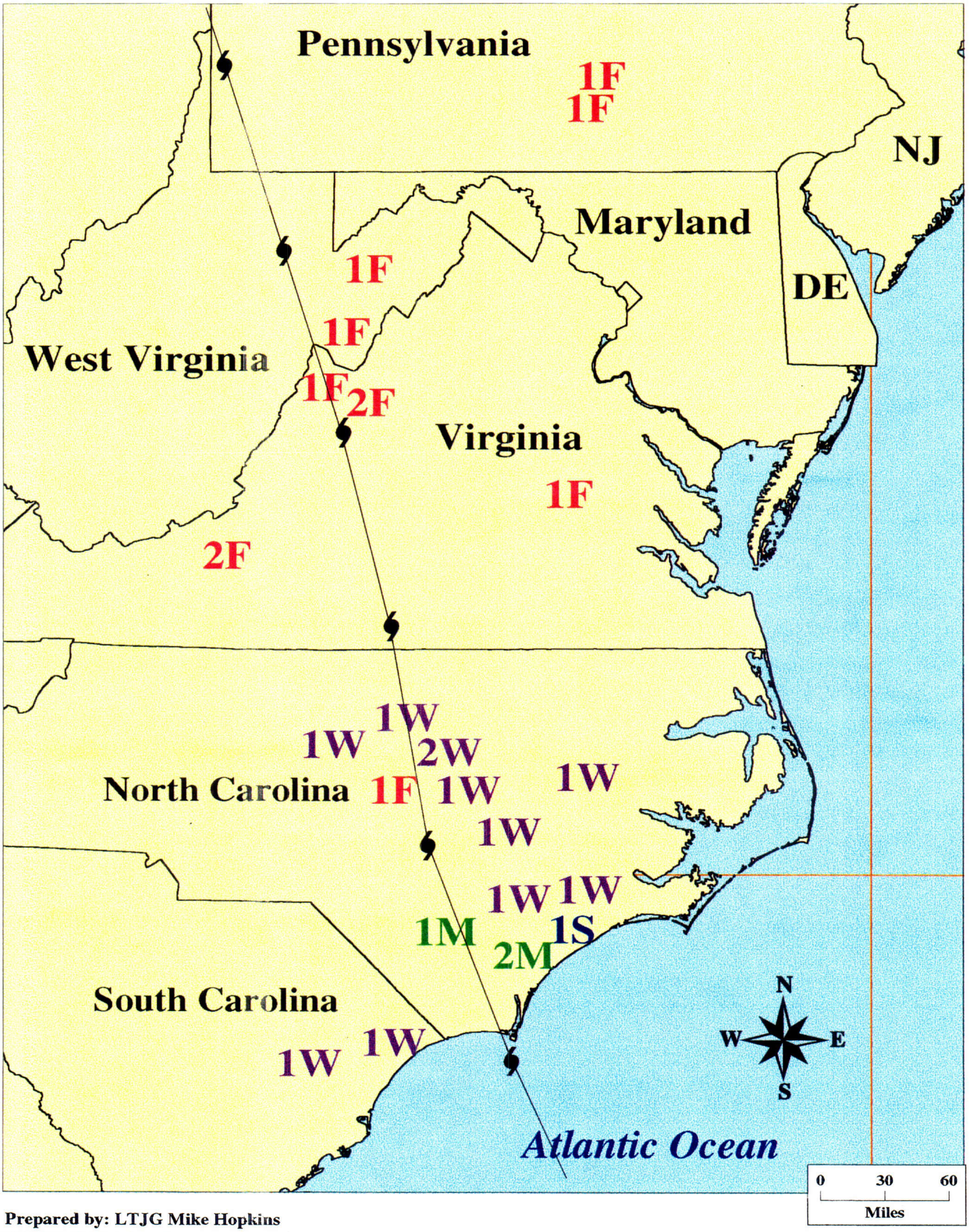
F = Flood-related death

W = Wind-related death

S = Storm surge-related death

M = Miscellaneous

U.S. Fran Deaths (26)



Prepared by: LTJG Mike Hopkins

TPC/NHC 14 Feb 97

APPENDIX B

Summaries of Site Visits

Appendix B
Summaries of Site Visits
by Bill Coulbourne and Eric Letvin

<u>TRIP REPORT</u>
<u>HURRICANE FRAN INLAND WIND ANALYSIS</u>
<u>Bill Coulbourne</u>

Date: 9/17/96
Location: Hwy. 17, N of Wilmington, NC

- Trees broken and leaning toward the NW indicating wind from the SE.
- Power lines are being re-routed through forks in large tree branches!!
- Topsail Elementary School, built 1991; escorted by Asst. Principal to look at interior damage to gym, wet ceiling tiles, were 300 people in gym at time of roof loss, standing-seam metal roof was attached to (aluminum) light-weight "C" sections installed over bar joists; one C channel rolled over from wind. No visible damage in inside of 12" -thick block wall. Local school district selects contractors; state school board prepares plans.
- Local lore says that almanac predicted category and time of both Bertha and Fran. Almanac says there is one more hurricane coming -- a Cat. 5. People are paying attention.
- Rt. 50, S of RT 17; mobile home damage near Surf City.
- No. of mobile home parks along route; no significant damage other than shingle damage
- Rt. 17 N; school has lost gym roof from Bertha; Onslow County; steel roof structure was still completely open.
- Power lines on S side of Rt. 17 were leaning toward the north but were still intact.

Location: New River Air Station, MCAS, Jacksonville, NC
Contact: Lt. Van
Observations/Notes:

- Station is near a small body of water; general area is very open.
- Lot of tree damage; many trees caused damage to structures.
- Hanger 504 had damage to concrete roof -- lost covering.
- Wind bent hanger door of Hanger 504.
- Siding pulled off Hanger 3905; some of this damage caused by Bertha.
- Siding pulled out around the self-tapping metal screws.
- Hole torn in metal roof of Hanger 3905; steel bent; hanger door was left open during storm allowing wind to get into structure.

- Sections of 4" -thick masonry pulled off walls at SE and NE corners; wall pulled off metal studs that had minimal attachments for block; block wall is almost 30' high; building is long and skinny -- aspect ratio of 15-20:1 and is about 80' wide.
- Family housing had mostly tree damage; some short posts that support carport roofs were uplifted by wind and then shifted off the brick support walls.
- At weather center, ASOS recorder lost power during storm, so wind readings were recorded by hand by reading wall-mounted wind gauge with a flashlight. Commercial power was lost, and backup generator was not started to run weather instruments. Weather commander said the anemometer was 20' high and was hot wire type. No confirmation.

Location: Camp Lejeune Marine Base, near Jacksonville, NC
Contact: Hill Hendricks and Jerry ?
Observations/Notes:

- Parachute loft building lost EIFS system on NE corner.
- Parachute loft building is 60' high.
- Self-tapping screws were used to attach gypsum board EIFS system to metal studs spaced 16" o.c. Jerry said they checked and found these screws were attached according to specs. No washers were used to attach the insulation and gyp board to the studs.
- Another building was inspected that uses the same EIFS system but is only one story high and sustained no damage.
- Barracks buildings built in early 1990's -- have 6" -thick precast concrete walkways on each of three levels. Precast walkways were constructed on site. Jerry believes these walkways were picked up by wind and dropped back onto cantilevered concrete supports.
- In one case of balcony support, the building edge was pulled out of a bolted connection. Temporary support has been placed between the back of the balcony and the concrete haunch above to keep the balcony from pulling further out of the bolts.
- No family housing was inspected
- No access to roof, but construction is supposed to be single-ply membrane over polysoc (?) insulation over precast concrete deck. Roof surface was pulled up by wind, but do not know to what extent. Jerry thought the membrane was supposed to be adhered.

Location: NWS office, Newport, NC

- No weather data available; person on duty said there was no gust recorder at the station.
- Contact names for additional data:
  DAPM -- Central Wills (has data from ASOS and other sites)
  SOO -- Carin Goodall (help retrieve wind data from radar)
  WCM -- Dan Bartholf
  Contact phone no for all 3 people is: 919-223-5122

Location: Cherry Point Marine Base, NC

Contact: Lt. Col. Rehrig

Observation/Notes:

- Many instances of shingle and siding loss.
- Wall buckled on 45-year-old building; building was being demolished and had no plywood sheathing in place. Roof framing is metal trusses. Not many metal clips holding brick onto wall framing.
- Standing-seam metal roofs OK.
- Failure in stucco finished; plywood covered fascias at top of 3-story.
- Some precast concrete walkway failure similar to Camp Lejeune.
- Base wants to do roof replacements with standing-seam metal.
- Older shingles (15 - 20 years) did OK; most are architectural type, maybe 240# +; most shingle loss was from 180# type.
- EPDM roofs that are 10 years old performed poorly. Roof of two hangers peeled back and exposed insulation. EPDM was secured with adhesive. Insulation was attached with screws. Flashing at edge of building was formed with a 2 x 12 attached with only one row of screws spaced 12" - 18" o.c. Some roofs, however, survived with no damage.
- EPDM installed in 1991 - 92 survived with no damage.
- Lost some metal siding that is only attached with clips. Metal appears to be about 22 - 24 ga.
- ASOS station -- no strip chart; station converted about 1.5 years ago.
- Didn't lose any storefront windows, and they were not covered to protect them.
- Base takes a lot of time just prior to a storm to pick up debris, tie down potential missiles including signs, etc.
- Base now has a problem of "fogging" for mosquitoes because of the large amount of water.

Location: Rt. 24 East of Clinton

- Tree damage showing up
- Tarps are on roofs, probably indicating damage by trees.

Date: 9/18/96
Location: Pope AFB, Fayetteville, NC
Contact: Mr. Campbell, Civil Engineering
Observations/Notes:

- Most damage done by trees; damage has been cleaned up for the most part.
- Barracks have flat roofs that are covered with single-ply membrane with no ballast; adhered and there was no loss.
- Housing area only had damage by trees and it was minimal.
- Power was out at 9:00 p.m. and was out 100% of the Fayetteville area.
- No damage to hangers or to overhead hanger doors.
- No damage to mobile housing or to schools.
- Did not lose water or sewer, or windows from debris.
- Weather office said sustained winds were 43kt, gusting to 58kt.
- Gusts occurred at 0300Z, 9/5/96
- Anemometer is 13' high, model no. FMQ-13; "hot wire" type.
- Several phone nos. for future reference:
  Weather Center: 394-6543
  Weather Maintenance: 394-2505
  Public Affairs: 394-4183

Location: Seymour Johnson AFB, Goldsboro, NC
Contact: Sgt. Denny
Observations/Notes:

- Did not get to tour the base; contact was a weather center person who did not know about damage levels, etc. other than reports.
- Sgt. Denny off the day of the visit; replaced by Sgt. Akers, a staff sgt. and a commander.
- Personnel offered that power was lost for a total of about an hour during the height of the storm.
- Two anemometers are in place on two runways. The highest wind recordings were taken from a backup system that the weather operaors had to manually retrieve every minute. There is some question about the complete accuracy of this method, but it's the only data that exists for this site. The primary anemometer was taken off line because the tower shut down and operators in the tower went home.
- No hanger or hanger door damage.
- Reports of glass breakage from debris; however, the base has a procedure for securing loose items before the storm, and this procedure was used in this event. I was told there are three levels of securing based on expected winds of 34kt, 50kt, and 65kt.
- Mobile home park sustained no damage other than lost skirting.
- Estimates of $6 + million in damages; must be in tree removal and damage done by trees, but in the drive through the base, this damage was not obvious.

- Anemometer station data being sent to me; verify height and type; believe it is "hot wire" type.
- Everyone in the center believes their winds were higher than 80 mph because of their experience; no support for this theory however.
- Radar during storm shows the eye closing up just south of Goldsboro about 0430Z, 9/6/96 and storm/rainfall intensity increase within a 6- to 12-minute period. Obtained copies of three radar images during this time period.

Traveling Locations:

- Rt. 24, East of Clinton, wind came from NE.
- East of Fayetteville; stand of trees that were vulnerable to wind had no damage.
- REPORT THOUGHT: Trees fall in any direction, but they fall in the direction of the primary winds; if one knew the direction of primary winds and the path, a prediction about which way trees would fall could be made with some certainty.
- Fayetteville, Rt. 24; almost no sign of damage; no broken windows; no trees over structures; some sign damage.
- Rt. 401N above Fayetteville; no sign of damage.
- Rt. 217 N south of Linden; house damaged by fallen tree (three hits).
- East of Erwin; trees blown down from the north toward the south, three mobile homes and one house.
- Rt. 55E in Dunn; part of metal roof/fascia blown off commercial structure.
- Rt. 55 E, east of I95; trees are lying down from the east toward the west.
- Structures with overhangs OK.
- Rt. 13E toward Goldsboro; 2/3 of barn destroyed; opening in barn caught the brunt of the east wind; barn located in open terrain.
- Many trees down in Goldsboro.
- Shingles blown off hip roof N of Goldsboro; shingles appear old.
- Rt. 111, east side of road; N of Goldsboro; tree fell through house.
- Rt. 117; Pikeville; trees blown down from east to west
- Rt. 117; west side of road; garage doors and masonry wall on commercial structure were blown in by wind from east. Shed roof blown up and lifted over structure. Owner said roof framing about 6 years old and single-ply memebrane about 1 yr. old. Masonry was 8"-thick unreinforced; height must be obtained from photos -- about 12' high. Membrane did not appear to be well-secured to the roof sheathing
- Rt. 117; commercial structure (Shell station) lost part of canopy.
- Vegetation, crop damage.
- Lucama; very large sign blown down facing south; wood posts rotten at bottom.

Date: 9/19/96
Location: G&O - Raleigh office
Contact: Gil Alligood
Notes:

- Agreed to put together a proposal for us that would provide the number and job skills of people from the Raleigh Office that could be made available for disaster-related projects; would include a rate for each person and a rate for a GPS survey crew, including the lease of GPS backpack equipment.
- Provided photos and photo log of Hurricane Fran damage east of Raleigh. He charged 3 hours plus photo cost of about $12.
- Met Will Bynum, a new CE whose resume we have.
- Met Richard Marshall, Director of Surveys, he is a pilot and has done aerial photography. From a scope of services I provide, he will put together an estimate for flying from Raleigh to Wilmington, NC, to photograph damage. He indicated that this could include crop, tree, and structural damage. He is going to do flyover this weekend to determine exactly what would be required. I told him that given the $100 per hour rate for plane and pilot, that he should go ahead with this flyover for 4 - 5 hours and charge to the 3651-014 charge number.
- Met Steve Glenn, NC Emergency Management Area B Coordinator. He came to the G&O office for a meeting. He relayed those areas that had sustained significant structural damage from what he knew. Reports of actual damage are provided by the counties. Given that I only have a few hours, he suggested a western trip toward Durham, Chapel Hill, etc.
- Glenn indicated also that a gym shelter near Dunn had lost a roof but that no one was hurt because people were moved to the interior of the building.

Location: NWS, NCSU, Raleigh
Contact: Kermit Keeter and George Lemons
Notes:

- G. Lemons provided me with summaries of the storm reported winds from Wilmington, NC, Newport, NC, Raleigh/Durham, NC, and Wakefield, VA.
- Also provided wind recording of the radar site showing 95- to 100-kt sustained winds at elevations of 6000 to 9000 ft. for some length of time at about 1:30 a.m. on 9/6/96.

Location varies -- travel west of Raleigh and return to airport:

- Very little damage of any kind along Rt. 40 West, Rt. 15/501 South, Rt. 54 West, Rt. 85 East, and Rt. 70 and 98 east toward Raleigh.
- Small area of damage along Rt. 54 West of mobile home.

TRIP REPORT
HURRICANE FRAN INLAND WIND ANALYSIS
Eric Letvin

Date: 9/17/96
Site Location(s): Shenandoah National Park-Skyline Drive, VA
Point of Contact: Sandy Rieves (Superindent), Bob Kremenaker (Chief of Natural and Cultural Resources, weather data), Doug Raeburn (Fire Management), Lynn Rockap (Public Affairs), Peggy Corbin (incident commander) Kevin McMurray, Sue Indlar
Materials Received: GIS maps of hurricane damage to Skyline Drive, fact sheet on Hurricane Fran and Shenandoah National Park Map
Materials Needed: Call Bob Krumenaker to ask for wind and weather data.
Phone: 540-999-3491, Bob_Krumenaker@nps.gov, 540-999-3400 general number for headquarters.
Observations of Damage: Damage to eastern side exposed gaps, Southern and Central sections of Skyline Drive sustained the most downed trees. Sandy Rieves initial estimate is 50 downed trees per acre, there are 190,000 acres in the National Park. Loft Mountain campground sustained heavy damage. Most of the downed trees were locusts and poplars, broad-leaved trees with shallow roots. Trees fell to the west. (See Fran Fact sheet)
Other: Need to send a copy of the final report to the park when completed.

Date: 9/17/96
Site Location(s): Wintergreen Ski Area, Wintergreen, VA
Point of Contact: John Kirchner (Manager of ski operations)
Materials Received: Wind data (inconclusive) from Trillium House (above main ski lodge)
Materials Needed: Call Dr. Micheals at State Climatological Office, Department of Environmental Sciences, University of Virginia at Charlottesville for Wind Data. Ed Trillium (540-361-1828).
Observations of Damage: Minor tree damage in the gap below the ski lodge around EL 2850'. Anemometer at the ski lodge is located at 3300' and at Trillium lodge at 3800'. Trees fell to the southwest.

Date: 9/18/96
Site Location(s): Lynchburg, VA
Point of Contact: Barry Martin, Lynchburg Fire Dept-Emergency Manager
Materials Received: None
Observations of Damage: Single-ply roof tarp blown off airport maintenance hanger. Viewed pictures of damage throughout the city, mostly downed trees on power lines and roads. Approximately 100 homes received minor damage.

Approximately 10,000 of the city's 65,000 residents were without power for several days.
Other: Barry said that the city received 46-48 mph sustained winds with 50-55 mph gusts, call Mike Emlaw-meterologist (V-Tech 1-800-221-2633) to acquire damage.

Date: 9/18/96
Site Location(s): Halifax, VA
Point of Contact: Bill Sleeper, County Administrator
Materials Received: None
Observations of Damage: None. Mr. Sleeper directed me to nearby South Boston, VA. No significant damage viewed in Halifax and between Lynchburg and Halifax.
Other: A meeting with FEMA officials and William Sleeper occurred on 9/18 to discuss crop damage to the area. Received cards from Josepth Anthony and Richard Parker (FEMA).

Date: 9/18/96
Site Location(s): South Boston, VA
Point of Contact: William Murray, Fire Chief
Materials Received: None
Observations of Damage: Mr. Murray escorted me to several places in the city that received damage. Notably, the east side of the city had a few homes with damage caused by falling trees. (The east side of the city is at a higher elevation that the remaining sections). Approximately 30-40 structures were damaged in the city of 7,000 people. A section of forest with trees that fell in several directions was viewed, possible tornado. Sections of a roof were blown off a commercial building on the west side of the city (see photos). Many of the trees that fell on homes were oaks; they fell to the south and southwest. Ninety percent of the city was without power for several days. Some of the trees that fell were diseased or weakened.

Date: 9/18/96
Site Location(s): Danville, VA
Point of Contact: Doug Young, Emergency Manager
Materials Received: Map of city with addresses of damaged homes caused by wind
Observations of Damage: Danville received significant flood damage; much of the city is in a floodplain. Approximately 20-30 structures received wind damage. Inspection of the city revealed that most of the repairs have been completed. The worst damage was to a park and bluff on the south bank of the Dan river. The bluff was exposed to the north due to its elevation. This area of the city did

not have many structures. Two streets on the north side of the city received wind damage, they were also exposed bluffs. Some of the trees that fell were diseased.

Date: 9/18/96
Site Location(s): Martinsville, VA
Point of Contact: Mr. Reese, Deputy escorted
Materials Received: Earlier fax from John Benn of damaged structures in the city
Materials Needed: None.
Observations of Damage: Most of the damage had been cleaned up. The "mulberry" section of the city (SE side) received the most damage. Damage was caused by trees falling on buildings. The homes that were damaged were generally very expensive, thus the owners cleaned up their property rapidly. A tree fell through the roof a building on the pistol range.

APPENDIX C

Adjustments to Recorded Wind Data

Appendix C -- Adjustments to Recorded Wind Data

Hurricane Fran Wind Speed Adjustments from Peak Gusts (mph)

LOCATION	RECORDED PEAK GUST	ADJUST TO 10 M HT. (1)	ADJUST TO 1 MIN. SUSTAINED (3)	ADJUST TO EXPOSURE C (4)	ADJUSTED SUSTAINED SPEED TO EXP. C	BEST ESTIMATE SUSTAINED SPEED
Frying Pan Shoals (w)	124	110	92	74	69	**74**
Wilmington, NC	86	86	68	68	68	**68**
Southport (w)	105	105	88	70	--	**70**
New River	94	98	77	77	72	**77**
Cherry Point	76	79	62	62	53	**62**
Cape Lookout (w)	82	82	68	54	56	**55**
Cape Hatteras (w)	56	56	47	38	35	**38**
Holden, NC (w)	77	77	64	51	--	**51**
Myrtle Beach, SC (w)	75	75	63	50	--	**50**
Pope AFB	67	72	57	57	57	**57**
Ft. Bragg (8)	74	77	61	61	48	**58**
Seymour Johnson AFB	80	86	68	68	73	**70**
Raleigh-Durham (8)	79	79	62	62	45	**54**
Greensboro	48	50	40	40	38	**40**
Greenville (9)	100	100	79	79	--	**~ 59**
Rocky Mount (10)	45	45	36	36	20	**--**
Elizabeth City	55	55	43	43	43	**43**
Norfolk, VA (2)	55	57	45	45	40	**45**
Danville	63	63	50	50	46	**50**
Richmond	53	53	42	42	37	**42**
Lynchburg	44	46	36	36	27	**36**
Wintergreen	41	41	32	32	--	**32**
Virginia Power	43	43	34	34	33	**34**
Dulles	40	40	32	32	29	**32**

Hurricane Fran Wind Speed Adjustments from Sustained Winds (mph)

LOCATION	RECORDED SUSTAINED WIND	ADJUST TO 10 M HEIGHT (6)	ADJUST TO 1 MIN. SUSTAINED (7)	ADJUST TO EXPOSURE C (4)
Frying Pan Shoals	99	78	86	69
Wilmington, NC	67	67	68	68
Southport	--	--	--	--
New River	67	72	72	72
Cherry Point	49	53	53	53
Cape Lookout	64	64	70	56
Cape Hatteras	44	44	44	35
Holden, NC	--	--	--	--
Myrtle Beach, SC	--	--	--	--
Pope AFB	49	57	57	57
Ft. Bragg	44	48	48	48
Seymour Johnson AFB	63	73	73	73
Raleigh-Durham	45	45	45	45
Greensboro	35	38	38	38
Greenville	--	--	--	--
Rocky Mount	20	20	20	20
Elizabeth City	43	43	43	43
Norfolk, VA	37	40	40	40
Danville	25	46	46	46
Richmond	37	37	37	37
Lynchburg	25	27	27	27
Wintergreen	--	--	--	--
Virginia Power	33	33	33	33
Dulles	29	29	29	29

NOTES TO TABULATED WIND SPEEDS

(1) Adjust gust speeds to 10-m height
over land: $V(33/H)^{0.085}$
water exposure: $V(33/H)^{0.080}$

(2) Average of:

Norfolk Airport -	46
Norfolk NAS -	63
Newport News -	59
Cape Henry -	63
Langley AFB -	52
Oceana NAS -	48
Average	55 mph, assume anemometer ht. of 20'

(3) Adjust speeds to 1 minute sustained. Over land: adjusted gust/1.3
Water exposure: adjusted gust/1.2

For comparison -- ASCE wind speed adjustments shown in Fig. C6-1 are for adjustments over land (Exposure C). To adjust gust to 1 min. sustained for hurricane force winds: 1.67/1.32 = 1.265
Use 1.265 as reduction factor which will increase 1 min. sustained winds

(4) Onshore/water flows x 0.80 to get equivalent exposure C conditions

(5) Average of :

Norfolk Airport --	30
Norfolk NAS --	41
Newport News --	36
Cape Henry --	46
Langley AFB --	35
Oceana NAS --	36
Average	37, assume anemometer ht. of 20'

Averaging times for the sustained winds may have varied but no reading is far from the average.

(6) Adjust sustained winds to 10 m height: $V(33/H)^{0.16}$

(7) Adjust to 1 minute sustained from 10 minute avg.
over water: 10 min. avg. x 1.10
over land: 10 min. avg. x 1.22 (from ASCE 7 graph that shows 1.32/1.08 = 1.22)

(8) Best estimate is 1.2 x sustained winds because gust factor is so large, convective activity is not representative of sustained winds

(9) High wind speed appears to be from convective activity. Speed could not be confirmed.

(10) Wind speed does not appear to be from a continuos record so this data was not included in the analysis.

APPENDIX D

Saffir-Simpson Scale

Appendix D

Saffir-Simpson Hurricane Scale[1]

Category One Hurricane -- Weak

Winds[2]: 75 - 95 mph (65 - 82 kt) at standard anemometer elevations. F-scale is 1.0 - 1.4. Damage is primarily to shrubbery, trees, foliage, and unanchored mobile homes. No real damage occurs to building structures. Some damage is done to poorly constructed signs.[3]

Storm Surge: Low-lying coastal roads are inundated, minor pier damage occurs, some small craft in exposed anchorages break moorings.

Category Two Hurricane -- Moderate

Winds: 96 - 110 mph (83 - 95 kt) at standard anemometer elevations. F-scale is 1.5 - 1.9. Considerable damage is done to shrubbery and tree foliage, some trees are blown down. Major structural damage occurs to exposed mobile homes. Extensive damage occurs to poorly constructed signs. Some damage is done to roofing material, windows, and doors; no major damage occurs to building structures.

Storm Surge: Coastal roads and low-lying escape routes inland are cut by rising water 2 - 4 hr before arrival of storm center. Considerable pier damage occurs, marinas are flooded. Small craft in unprotected anchorages break moorings. Evacuation of some shoreline residences and low-lying island areas is required.

Category Three Hurricane -- Strong

Winds: 111 - 130 mph (96 - 113 kt) at standard anemometer elevations. F-scale is 2.0 - 2.4. Damage occurs to shrubbery and trees: foliage is blown off trees, large trees are blown down. Practically all poorly constructed signs are blown down, some roofing material damage occurs, some window and door damage occurs, and some structural damage occurs to small residences and utility buildings. Mobile homes are destroyed . There is a minor amount of curtainwall failure.

Storm Surge: Serious flooding occurs at the coast with many smaller structures near the coast destroyed. Larger structures are damaged by battering of floating debris. Low-lying escape routes inland are cut by rising water 3 - 5 hr before the storm center arrives. Terrain continuously lower than 5 ft (1.5 m) above sea level may be flooded inland 8 mi (12.9 km) or more. Evacuation of low-lying residences within several blocks of the shoreline may be required.

Category Four Hurricane -- Very Strong

Winds: 131 - 155 mph (114 - 135 kt) at standard anemometer elevations. F-scale is 2.5 - 2.9. Shrubs and trees blown down, all signs are down. Extensive roofing material damage occurs, extensive window and door damage occurs, complete failure of roof structures occurs on many small residences, and complete destruction of mobile homes occurs. Some curtainwalls experience failure.

Storm Surge: Terrain continuously lower than 10 ft (3 m) above sea level may be flooded inland as far as 6 mi (9.7 km). Major damage occurs to lower floors of structures near the shore due to flooding and battering action. Low-lying escape routes inland may be cut by rising water 3 - 5 hr before the storm center arrives. Major erosion of beach areas occurs. Massive evacuation of all residences within 500 yd (457 m) of the shoreline may be required and of single-story residences on low ground within 2 mi (3.2 km) of the shoreline.

Category Five Hurricane -- Devastating

Winds: Greater than 155 mph (135 kt) at standard anemometer elevations. F-scale is 3.0 or greater. Shrubs and trees are down, roofing damage is considerable, all signs are down. Very severe and extensive window and door damage occurs. Complete failure of roof structures occurs on many residences and industrial buildings. Extensive glass failures occur, some complete buildings fail, small buildings are overturned and blown over or away, and complete destruction of mobile homes occurs.

Storm Surge: Major damage occurs to lower floors of all structures located less than 15 ft (4.6 m) above sea level and within 500 yd (457 m) of the shoreline. Low-lying escape routes inland are cut by rising water 3 - 5 hr before the storm center arrives. Massive evacuations of residential areas situated on low ground within 5 - 10 mi (8 - 16 km) of the shoreline may be required.

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[1] The Saffir-Simpson Hurricane (SSH) Scale does not apply to the Pacific Islands.

[2] Definition of a sustained wind (from Fujita and Simpson, 1972). A sustained wind is one that persists for the minimum time period to establish optimal dynamic forces on a nominal building structure.

[3] T. Fujita, 1971: "Proposed Characteristics of Tornadoes and Hurricanes by Area and Intensity," University of Chicago (SMRP) Research Paper No. 91.

APPENDIX E

Structural Damage

Appendix E

Structural Damage*

North Carolina

COUNTY	% SINGLE-FAMILY HOMES	% MOBILE HOMES	% APARTMENTS
Brunswick	.40	1.2	67.3
Columbus	.08	.26	4.08
Bladen	.67	1.7	0
New Hanover	4.1	5.1	2.3
Pender	9.5	9.5	12.2
Onslow	3.1	5.0	2.9
Carteret	.06	.61	0
Jones	.11	.1	0
Duplin	.69	2.5	0
Lenoir	.43	.02	0
Greene	0	0	0
Wayne	.68	.59	.02
Sampson	.66	.93	.18
Cumberland	.16	.06	.25
Harnett	.14	.45	0
Johnston	1.5	3.6	1.7
Wilson	.14	.06	.02
Wake	.82	.63	.54
Durham	.38	.13	0
Nash	.31	.27	0
Franklin	.21	.32	0
Vance	0	0	0
Craven	.02	.42	.55
Granville	.07	0	0
Person	0	0	0
Orange	.43	.27	.03
Robeson	.15	.27	0
Pitt	.05	.13	0

*Source: American Red Cross

Virginia

COUNTY	% SINGLE-FAMILY HOMES	% MOBILE HOMES	% APARTMENTS
Halifax	.03	.04	0
Pittsylvania	.06	.05	0
Henry	.05	0	.10
Rockbridge	.11	0	.62
Augusta	.14	.20	0
Rockingham	.69	.10	.34

APPENDIX F

Vegetation / Crop Damage

Appendix F

Vegetation / Crop Damage*

North Carolina

COUNTY	% CROPS DAMAGED	COUNTY	% CROPS DAMAGED
Alamance	17.6	Martin	34.9
Alleghany	34.2	Montgomery	36.3
Beaufort	4.8	Muare	27.8
Bertie	5.0	Nash	36.1
Bladen	47.9	New Hanover	73.5
Brunswick	65.0	Onslow	N/A
Buncombe	38.0	Orange	46.8
Cumberland	40.6	Pamlieu	49.2
Davidson	17.3	Pasquotank	6.8
Davie	4.4	Pender	54.9
Duplin	38.7	Perquinans	25.0
Durham	7.9	Person	13.0
Carteret	19.1	Pitt	30.0
Caswell	12.9	Randolph	24.6
Chatham	43.6	Richmond	10.4
Columbus	52.2	Rockingham	18.9
Craven	N/A	Robeson	23.2
Edgecombe	26.4	Samson	36.0
Franklin	12.0	Scotland	22.4
Gates	6.8	Stokes	8.8
Granville	18.3	Tyrell	(see Dare)
Greene	20.8	Dare	14.8
Halifax	11.9	Vance	15.9
Harnett	10.5	Wake	5.4
Hoke	21.1	Warren	41.7
Hyde	29.4	Washington	5.1
Johnston	40.0	Wayne	25.6
Jones	17.1	Wilkes	1.6
Lenoir	44.6	Wilson	28.4

*Source: U.S. Department of Agriculture, North Carolina State Farm Service Agency Office

APPENDIX G

Comparison of MEOWs to Adjusted Sustained Wind Speeds

Appendix G

Comparison of Meows to Adjusted Sustained Wind Speeds*

MEOW -- Advisory No. 49, 121-mph sustained speed, 14-mph forward speed

RANGE OF MEOW SPEED (mph)	ADJUSTED SUSTAINED SPEED (mph)	DIFFERENCE (AVG. - SUSTAINED)	% DIFFERENCE
92 - 108	51	41	44.6
	73	19	20.6
	68	24	26.1
	75	17	18.5
	70	22	23.9
75 - 91	--	--	--
58 - 74	58	0	0
	57	1	1.7
	54	4	6.9
	70	-12	-20.7
	62	-4	-6.9
	55	3	5.2
	59	-1	-1.7
40 - 57	40	0	0
	50	-10	- 25.0
	36	4	10.0
	38	2	5.0
	43	-3	-7.5
	32	8	20.0
AVERAGE			**6.7**

* Comparison is made between adjusted sustained wind speed and the average of the MEOW speeds in each range.

Note: All numbers are positive unless otherwise indicated.

MEOW -- Advisory No. 49, 98-mph sustained speed, 14-mph forward speed

RANGE OF MEOW SPEED (mph)	ADJUSTED SUSTAINED SPEED (mph)	DIFFERENCE (AVG. - SUSTAINED)	% DIFFERENCE
75 - 92	75	0	0
	73	2	2.7
	70	5	6.7
	68	7	9.3
	51	24	32.0
58 - 74	58	0	0
	59	-1	-1.7
	54	4	6.9
	70	-12	-20.7
	62	-4	-6.9
	59	-1	-1.7
	55	3	5.2
40 - 57	40	0	0
	50	-10	-25.0
	36	4	10.0
	38	2	5.0
	43	-3	-7.5
	32	8	20.0
AVERAGE			**1.9**

* Comparison is made between adjusted sustained wind speed and the average of the MEOW speeds in each range.

Note: All numbers are positive unless otherwise indicated.

APPENDIX H

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Appendix H

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