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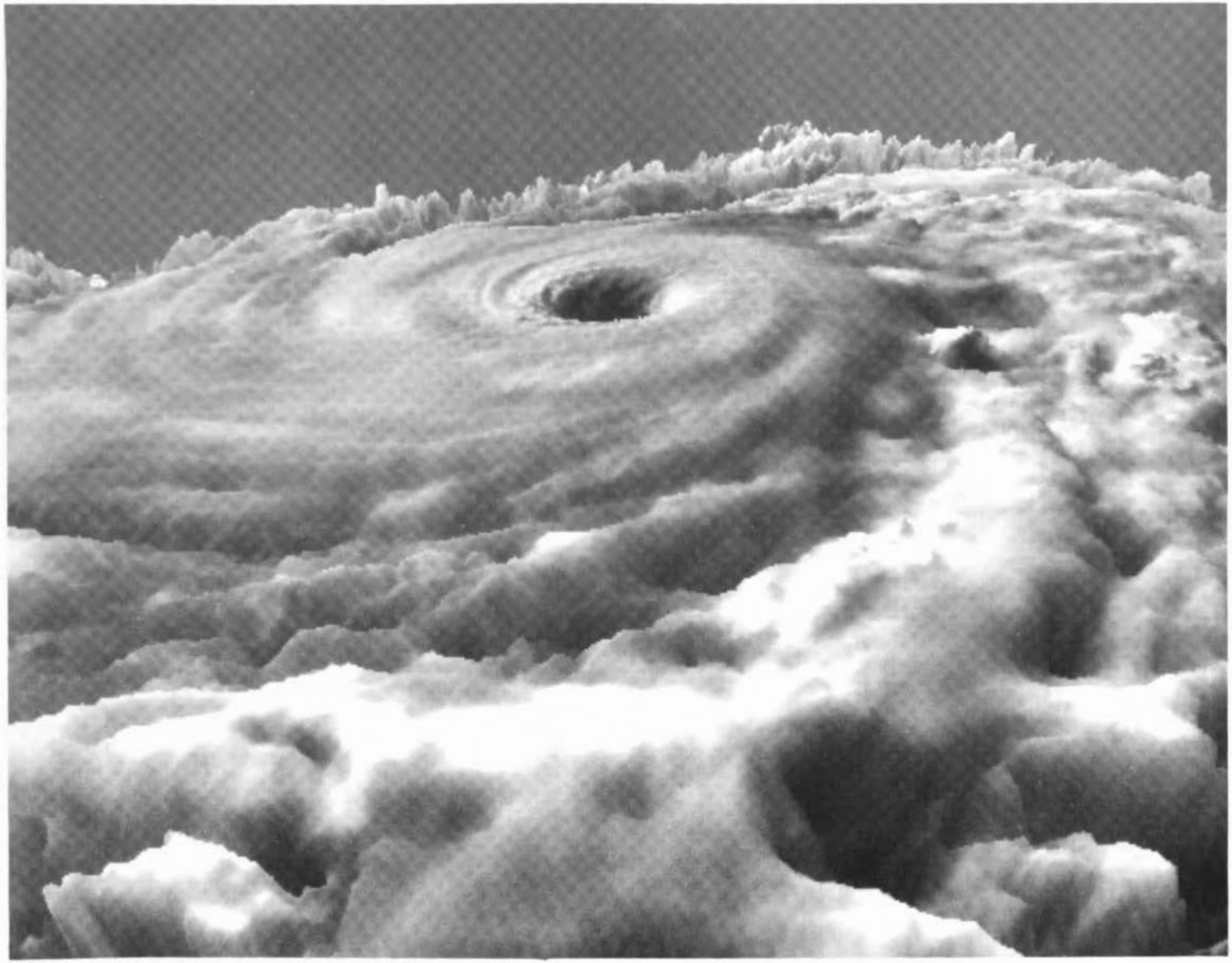

Perspective view of Hurricane Diana from Tiros-N visible and infrared data on September 10, 1984, at 10:00 p.m. EDT. Source: Hasler et al., 1984.

Hurricane Diana North Carolina September 10-14, 1984

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For:
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CONTENTS

1

INTRODUCTION AND OVERVIEW

Diana was the first full-fledged hurricane to strike the east coast of the United States in five years. Although initially a category 3 hurricane on the Saffir-Simpson scale, it stalled offshore losing strength for more than 24 hours. By the time it made final landfall early on September 13, 1984, Diana had become a relatively weak, borderline category 1/category 2 storm. It caused limited damage to coastal districts of New Hanover County and Brunswick County, North Carolina, an area that had been heavily damaged by Hurricane Hazel 30 years earlier in 1954. Figure 1.1 shows the storm's track from September 8 to September 16.

Three aspects of Hurricane Diana are of particular interest: (1) its complex meteorological and hydrological characteristics; (2) the fact that it struck an area where there have been significant efforts to mitigate the effects of hurricanes; and (3) the long-drawn-out warning, evacuation, and sheltering process. Study team members surveyed damage and responses in North Carolina (Figure 1.2) between September 16 and September 21. One member of the team briefly visited the coast of South Carolina and surveyed building damage in coastal areas, as reported in Chapter 3. A significant number of vacationers in the Grand Strand area of South Carolina were threatened by Diana, but no comprehensive analysis of the hurricane in South Carolina is attempted in this report.

METEOROLOGY

The storm that was to become Hurricane Diana formed in the remnants of an old polar trough on September 8, 1984. By the time it approached the North Carolina coast on September 11, it was a dangerous hurricane. Diana then moved erratically and began to vary in intensity. These changes were most likely due to a combination of factors, including weak upper-atmosphere steering currents, infusions of colder air, passage over colder water, and changes in the internal organization of the storm. While it is not unusual for hurricanes to behave in this manner, they are very difficult to forecast accurately. Despite these uncertainties, Diana was well forecasted.

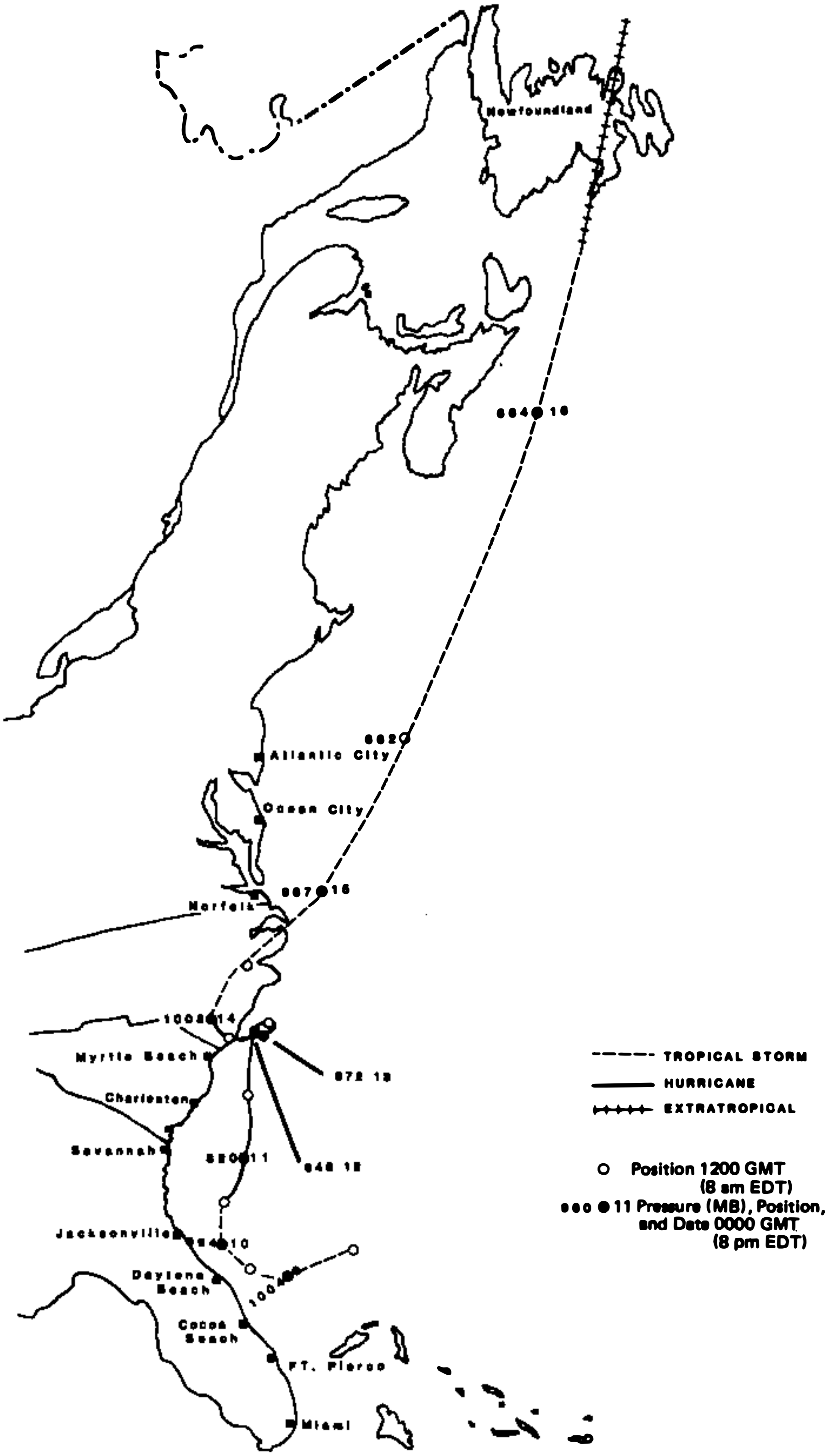


FIGURE 1.1 Track of Hurricane Diana, September 8-16, 1984.

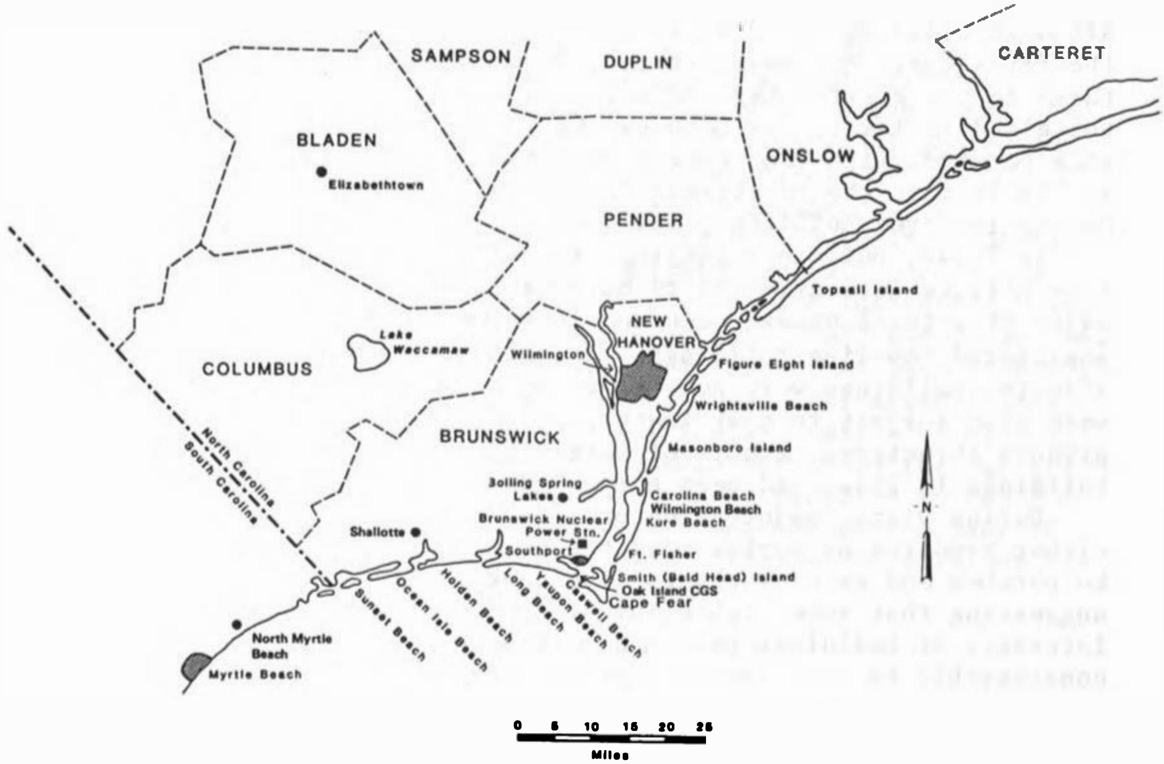


FIGURE 1.2 The Cape Fear region of North Carolina.

STORM SURGE AND COASTAL PROCESSES

Hurricane Diana had a minor effect on coastal areas because of a low storm surge. Fortuitously, the hurricane lost intensity as it moved onshore on a falling astronomical tide. The result was a peak surge level of only 5.1 ft above mean sea level. At Carolina Beach, North Carolina, which experienced the brunt of the storm, the peak surge was 4.5 ft above mean sea level. Surging waters flooded some low-lying streets during hurricane landfall, but no buildings were directly affected. The berm was eroded away at Carolina Beach, and the beach retreated landward by as much as 50 ft in some areas. There was some erosion and scarping of the seaward dune face where it was fronted by narrow beaches, but there was no direct overtopping of swash or over-washing of sand in this developed community. The effects of Hurricane Diana on the immediate coastline were similar in nature and extent to those generated by an average winter northeaster.

BUILDINGS AND STRUCTURES

Although Diana was of similar strength to Hurricane Alicia, which struck the Texas coast one year earlier, damage to buildings and other structures in the greater Cape Fear region was but a small fraction of that sustained in Texas. In both events the majority of damage was attributable to wind, with wind speeds approaching those of a 50-year storm. It is likely that the relatively light wind damage in North Carolina was due to improved building practices.

In Texas, buildings ranging from single-family dwellings to high-rise offices were affected by hurricane-force winds, but most of the major structural damage occurred in nonengineered or marginally engineered low-rise buildings. In North Carolina, virtually all affected buildings were nonengineered or marginally engineered. They were also subject to a stringent, prescriptive building code intended to produce structures capable of safely resisting 120-mph winds. Such buildings in Texas had been subject to very little building control.

During Diana, major structural damage occurred in buildings that either predated or contravened the North Carolina code. Serious damage to porches and eave overhangs also took place in many other houses, suggesting that some tightening of code provisions may be required. The interiors of buildings with minor structural damage often were damaged considerably by rain due to loss of shingles or other roofing materials and penetration of water through vents and windows.

Relatively few mobile homes were affected by Diana, and nearly all mobile homes were well tied down. Several suffered severe damage even though they did not overturn. Some fishing piers and docks were damaged by wave action, and many signs were destroyed or seriously damaged by wind.

One major building in South Carolina was damaged by winds of about 50 to 60 mph. This eight-story building in North Myrtle Beach lost much of its exterior cladding. Close inspection of the cladding system showed that it was unsuitable for hurricane-prone locations.

LIFELINES

Hurricane Diana had very little impact on the integrity of lifeline structures. Most power-related problems were caused by strong winds that downed main transmission lines, power poles, and hookup wires to individual homes. Most serious damage to telephone lines was attributable to high winds and fallen trees. An automatic shutdown of the Brunswick Nuclear Power Station during the storm proved to be an efficient safety precaution.

Heavy rain associated with Diana subjected some small embankment dams to critical flows and overtopping. Their drainage pipes were clogged by fallen branches and debris; consequently there was a loss of shear strength brought about by seepage into the dam materials.

The collapse of an old elevated water tank constituted the most spectacular failure of an engineered structure. The failure was probably induced by vibrations and excessive cyclic stresses, possibly caused by a tornado or wind-induced vortices.

ECONOMIC AND SOCIAL COSTS

Hurricane Diana arrived at an opportune time for the Cape Fear region. By mid-September the summer vacation population had dwindled to a relative handful, thus easing problems of warning and evacuation. Had the storm struck a month earlier, up to 135,000 additional shorefront occupants might have been affected (i.e., approximately twice the number present, throughout both counties, during mid-September).

No comprehensive count of human casualties attributable to Diana is available, but they were believed to be relatively few. Local newspapers reported that the storm indirectly caused four deaths and a small number of injuries. Property damage was also inflicted, but losses were small compared with that of other recent hurricanes that have struck the United States (such as Hurricanes Alicia and Iwa). Estimated losses of approximately $80 million were reported for a six-county area of North Carolina (Table 1.1). Agricultural crop damage accounted for one third of the total. Insurance industry representatives expected to pay $36 million in claims. Although many observers commented on the lack of extensive damage to buildings, a Presidential disaster declaration was issued on September 21, 1984.

TABLE 1.1 Summary Damage Estimates for Hurricane Diana in North Carolina

	Damage (millions of dollars)
Private property	
Housing	30.1
Business	5.1
Agriculture	26.5
Public property	
State and local government	17.2
Total	78.9

Note: Includes New Hanover, Brunswick, Columbus, Pender, Bladen, and Sampson counties.

Source: State Coordinating Officer, North Carolina Emergency Management, personal communication, 1984.

EMERGENCY MANAGEMENT AND HAZARD MITIGATION

At first glance the fact that few lives were lost and few significant injuries sustained during Hurricane Diana speaks well of the warning and evacuation systems. Yet there is reason to believe that this fortunate outcome was as much due to the modest intensity of the storm as to the efficiency of emergency management procedures.

Potentially serious flaws in preparedness emerged but did not mature into full-fledged problems. For example, initial public evacuation decisions were delayed by several hours against the advice of the National Weather Service. This was done partly because county and municipal emergency managers correctly assumed that there were relatively few people in exposed coastal communities, and partly because they waited for the state government to take the lead by declaring a state of emergency. Further delays were occasioned by scattered disputes among local government units and personnel over the possession of legitimate authority to "order" evacuations. None of the many public schools or other buildings that were used as emergency shelters had been officially surveyed to determine their safety during hurricane wind and flood conditions. Information on the probability of the hurricane's impact was discontinued approximately 44 hours before landfall. There is no evidence that this information played a significant part in triggering or retarding public and private decisions to evacuate.

Many people exposed themselves to unnecessary hazards by returning to oceanfront areas after Diana withdrew from contact with the coast on the night of September 11-12. Hurricanes frequently follow complex looping tracks near land, and there is the potential for major losses on some parts of the U.S. coast if evacuated areas are prematurely reoccupied and a storm returns unexpectedly. It is possible that National Weather Service advisories issued from Wilmington during part of the morning of September 12 did not sufficiently emphasize the need to stay away from oceanfront areas, but National Hurricane Center advisories and local Wilmington statements generally were accurate reflections of the rapidly changing, and often uncertain, state of forecast knowledge. Some local emergency managers and other officials failed to prevent the premature return of evacuees and found themselves unable to reevacuate beach communities when the hurricane turned, one again, toward shore. Other emergency managers steadfastly resisted attempts to reoccupy shorefront areas while the hurricane posed a threat.

The long-term effect of Diana on actions to mitigate hurricane losses in North Carolina is likely to be minimal. Opinions about the adequacy of building codes and other measures designed to reduce losses differ among local leaders and hazard professionals. On balance, most agree that current plans to strengthen mitigation should be carried forward undiminished. The study team's judgment is that, while Hurricane Diana produced some grounds for optimism about the effectiveness of existing measures for mitigating wind damage, it was a partial and inconclusive test of general mitigation efforts for hurricanes.

2

METEOROLOGICAL ASPECTS AND COASTAL PROCESSES

METEOROLOGY

Introduction

Hurricane Diana generated great concern as it approached the coast of North Carolina on the night of September 11-12, 1984, because of its similarities to the catastrophic Hurricane Hazel, which struck the area on October 15, 1954. Diana followed a similar path, was nearly as intense, and arrived at a comparable high tide. Unlike Hazel, however, Diana became almost stationary when its center was 15 to 20 miles offshore. It subsequently turned eastward, slowly made a clockwise loop, and again approached shore on the night of September 12-13. In the interval before Diana's second onset, the storm's maximum winds decreased significantly and high tides were replaced by low tides. The combination of reduced intensity and low tide suppressed the effect of Diana's storm surge and resulted in damages that were much less than occurred during Hurricane Hazel.

Meteorological Situation

Figure 1.1 shows the track of Hurricane Diana (Gerrish, 1984). Prior to September 8, a cold front had moved through the southeastern United States and formed a quasistationary frontal trough north of the Bahamas. In the western end of this trough, a storm developed on September 8. At the time, there was a cold low at high levels in this area and the storm was very poorly organized.

Like other storms that form under similar circumstances, Diana intensified rather slowly. However, these are unusual conditions for the formation of tropical storms. Most tend to develop in rather homogeneous tropical air where there is relatively little shear in the horizontal winds with height.

Early on September 8, convection became better organized and a nearby ship reported 40-mph winds at 8 a.m. EDT. Later in the day, satellite and aerial reconnaissance confirmed that the system had reached tropical storm strength and it was named Diana.

Diana formed in an area where the surrounding wind fields exerted only a weak steering effect. This made it difficult to forecast the storm's movement. It moved slowly northwesterly at first, on a course parallel to the Florida coastline and about 50 miles offshore. On reaching the latitude of Daytona Beach, it curved toward land for a short distance before resuming a generally northward course for 48 hours, parallel to the coast.

Diana had formed in an old trough of low pressure originally filled with cold, dry polar air that had slowly warmed and acquired moisture. Warmth and moisture are two of the necessary ingredients for the development of tropical storms, and Diana continued to intensify slowly as the sea surface temperatures rose and additional moisture was transferred from the ocean to the lower layers of air. By 8 a.m. on Tuesday, September 11, the maximum winds were above 110 mph. It was now a very dangerous hurricane that was projected to cross the coast near where Hurricane Hazel made landfall in 1954. Hazel crossed the coast near the border but devastated the coast from Myrtle Beach, South Carolina, to well northeast of Wrightsville Beach, North Carolina (Figure 1.2).

The hurricane continued to intensify during September 11 and reached its greatest intensity at 8 p.m., with maximum winds of 130 mph. The center was within 15 to 20 miles of the coast and nearly stationary (Figure 2.1). The diameter of the eye was reported by reconnaissance to be 14 miles, and the eyewall with the maximum winds lay over the outer islands (Figure 2.2). The anemometer at Oak Island Coast Guard Station measured sustained winds of 115 mph at 7:45 p.m. (instrument elevation, 66 ft). An observer reported the anemometer registered 115 mph continuously for 6 minutes, so it is likely that gusts were considerably stronger. Fort Fisher Air Force Station reported gusts in excess of 115 mph at 2:10 a.m. on Wednesday, September 12.

Late on Tuesday, September 11, the already weak steering currents weakened still further. Prior to that time the integrated wind fields throughout the lower 40,000 ft of the atmosphere and within 500 miles of Diana were blowing south to the west of the storm and north to the east. Since the east side winds were slightly stronger, the hurricane moved generally northward at slow speed. Now the opposing air currents became almost balanced. In the meantime, other changes occurred north and south of the storm so that the net motion in these two areas was slowly toward the east. As a result, Diana slowed near the mouth of the Cape Fear River and began to move east. Thereafter, atmospheric adjustments north of the center caused pressure to rise throughout at least the lower half of the atmosphere and progressively shifted wind directions around Diana. This produced the slow clockwise loop that ended a day later with Diana again heading toward the mouth of the Cape Fear River, this time coming from the east (Figure 2.1).

Nearshore and Landfall Storm Characteristics

Diana's maximum winds were about 130 mph over the water when the hurricane first approached the coast (September 11-12) and about 90 mph on the second and final approach (September 12-13) (Figure 2.3). On these

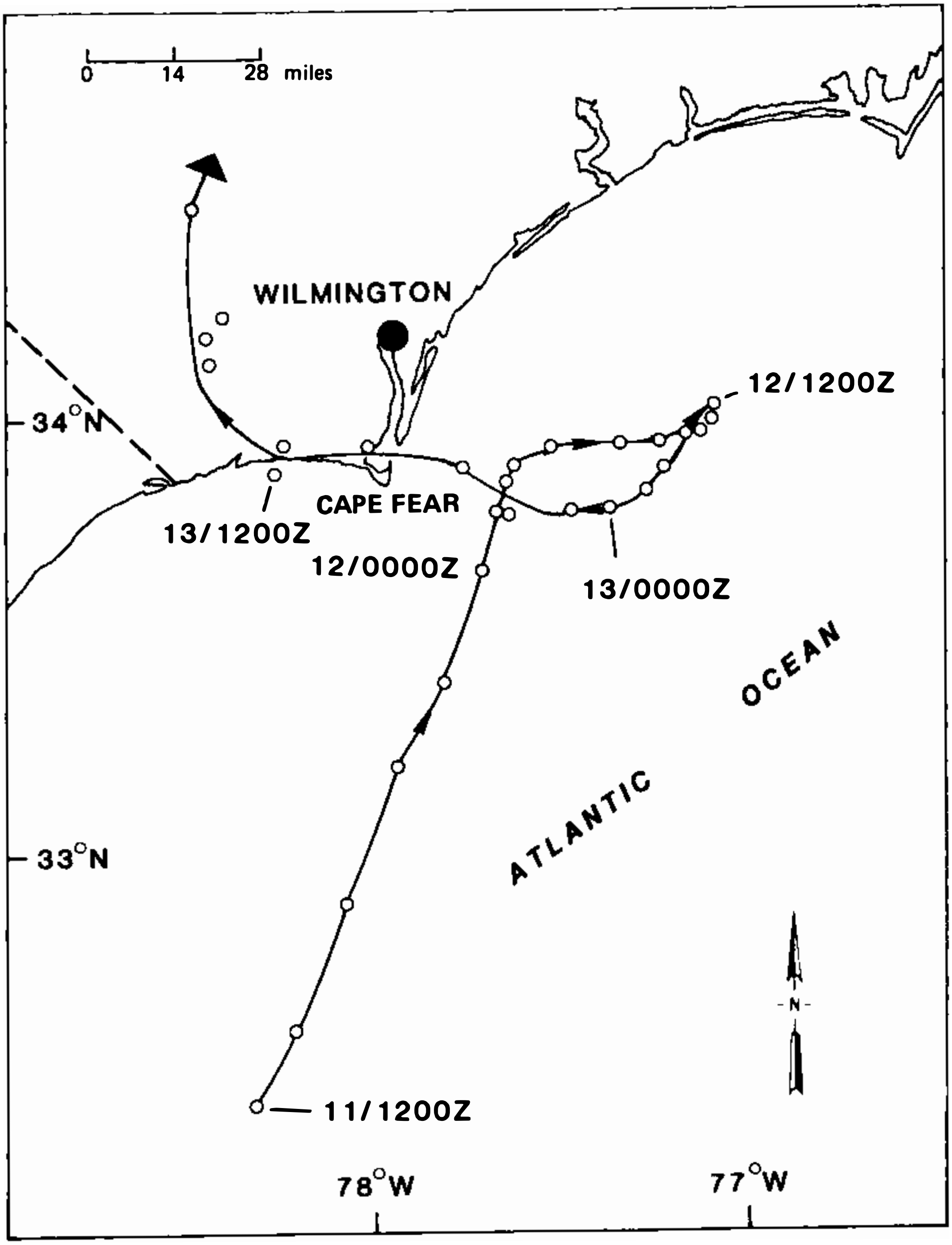


FIGURE 2.1 Nearshore track of Hurricane Diana, September 11-13. Over land the center was diffuse and could be reported over a relatively large area.

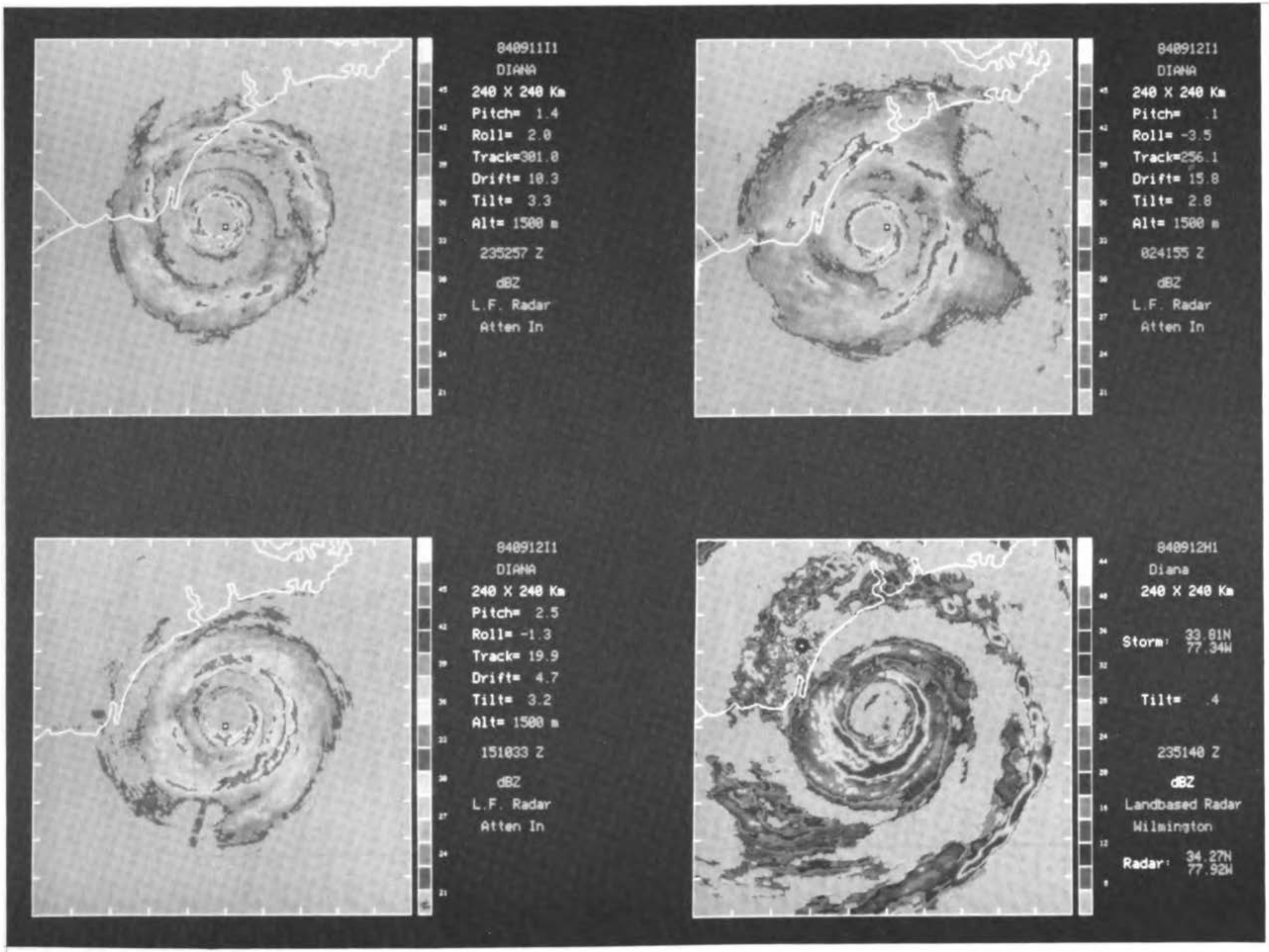


FIGURE 2.2 Radar imagery of Hurricane Diana, September 11-12.

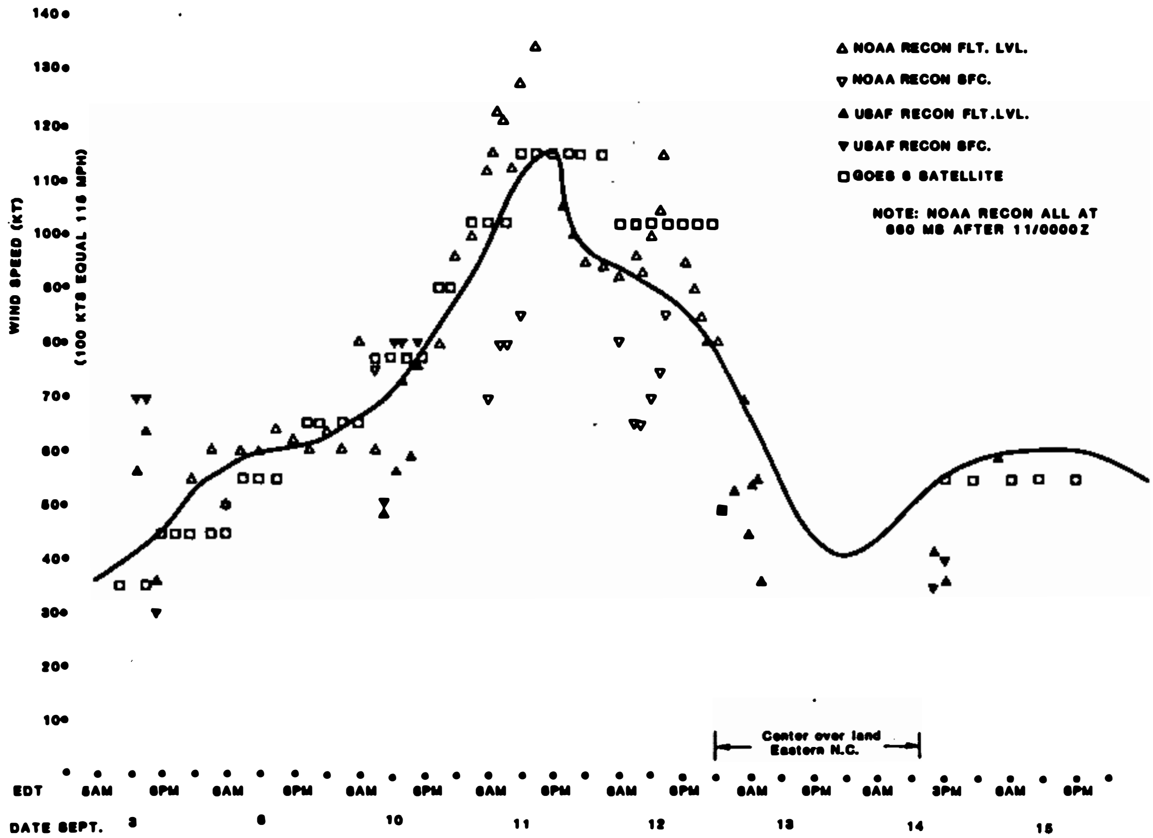


FIGURE 2.3 Maximum wind speeds in Hurricane Diana.

two occasions the storm's central pressures were 949 mb and 977 mb, respectively (Figure 2.4). Both sets of measurements were made over water by aerial reconnaissance. Some of the aircraft were also measuring and recording wind data every second at flight level. This made it possible to approximate the wind fields at both times (Figures 2.5 and 2.6). However, these analyses were probably not representative of wind speeds over land. For example, winds were measured at about 5,000 ft, where they were probably stronger than at the surface. They were also recorded over water, without the frictional drag exerted by land. Nor were measurement periods standardized. Figure 2.5 is based on a 3-hour record, whereas Figure 2.6 illustrates a 2-hour record. In each case Diana was moving during the period, and both figures indicate wind speeds relative to the center of the storm rather than to fixed geographical coordinates.

Nonetheless, taken together the figures show relative differences in wind speed and the areal expanse of damaging winds for each approach. For example, maximum winds in the earlier approach were about 18 miles (16 nautical miles) from the center, compared with 32 miles (28 nautical miles) on the second occasion. On the first pass, 50-knot winds (58 mph) extended out about 120 miles to the northeast, 140 miles to the

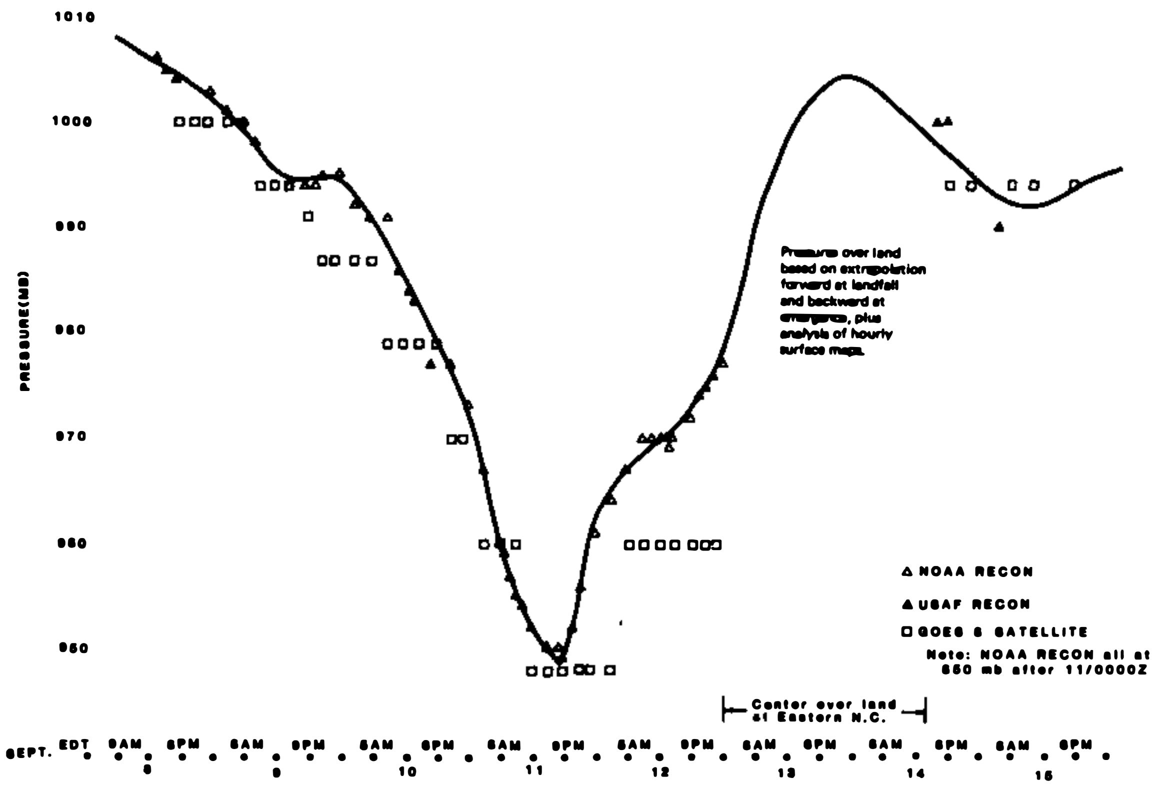


FIGURE 2.4 Central pressures in Hurricane Diana.

east, 110 miles to the south, and 85 miles to the southwest. During the second approach, 50-knot winds extended 160 miles to the northeast, 145 miles to the east, 90 miles to the southeast, and 60 miles to the south, and the wind field was more asymmetric. Although the 50-knot winds extended farther to the northeast on the second occasion, they did not extend as far to the southeast or south.

Additional information about the maximum winds over land, minimum pressures, rainfall, and tides is given in Tables 2.1 through 2.3, which were prepared by the National Hurricane Center (Lawrence and Clark, 1985). The Brunswick Nuclear Power Station, between Wilmington and the coast, had its highest sustained winds (1 minute) of 78 mph, with gusts to 95 mph, on Wednesday night and Thursday morning (September 12-13) near midnight.* Speeds dropped to less than 8 mph as the center passed over the station and then increased again. This time maximum winds were sustained at 75 mph, with gusts to 92 mph at about 5:30 a.m. The

*The fastest minute and maximum gust wind speeds were read from a strip recording prepared by Carolina Power and Light representatives. Brian McFeaters (North Carolina Power and Light, personal communication) reported that the recorder had a lag that might have kept its response from being faster than about 30 seconds.

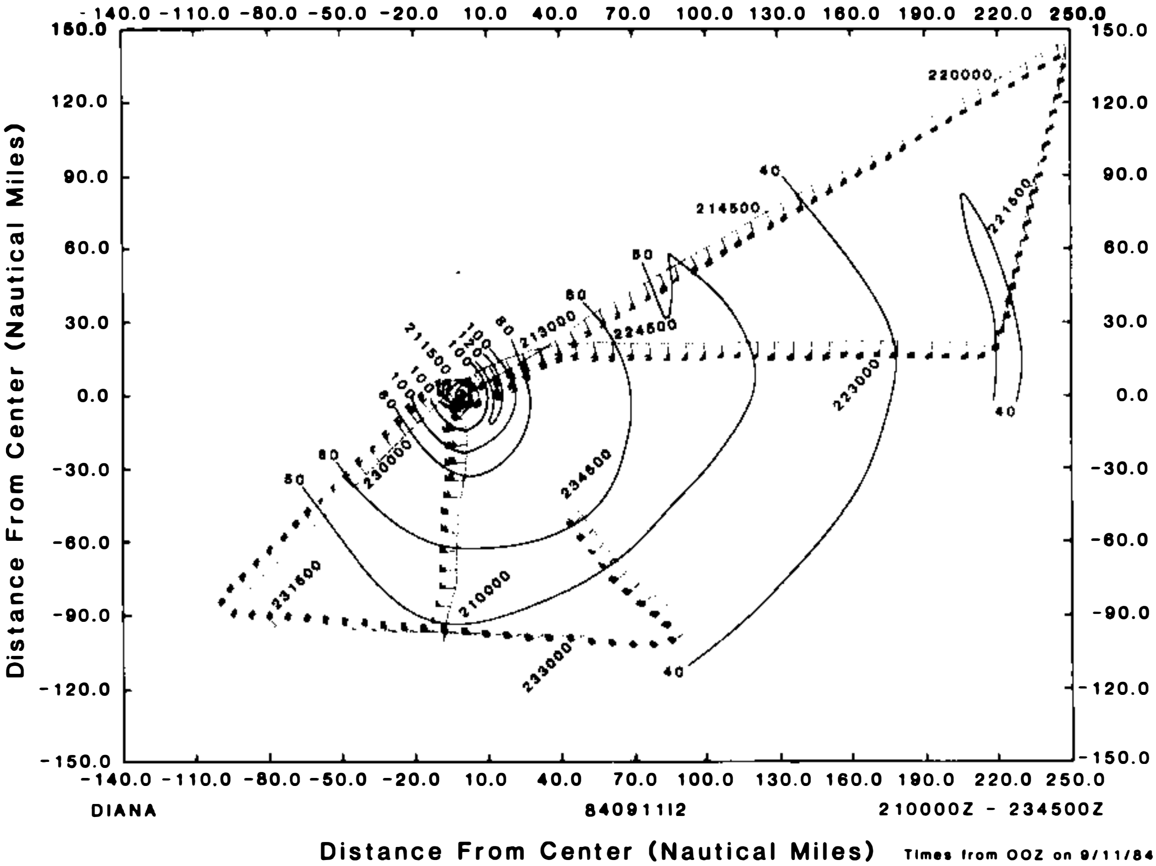


FIGURE 2.5 Winds of Hurricane Diana at 5,000 ft, September 11 (barbs and isolines of equal wind speed in knots). Short crossbars equal 5 knots; long crossbars equal 10 knots; and penants equal 50 knots.

anemometer was mounted at the 33-ft level with good exposure about 4 miles from the ocean.

All evidence indicates that damage would have been much greater if the storm had gone inland on the night of Tuesday, September 11. Maximum winds were much stronger than on September 12-13, and maximum wind forces would have been more than twice as great. Thus, the storm surge would have been greater on the first pass even without the added problem of high tide.

The center of Diana crossed the coast near the mouth of the Cape Fear River about 3:00 a.m. Thursday, September 13 (Figure 2.1). According to the National Weather Service, "The storm center passed over Green Swamp; Lake Waccamaw; just east of Elizabethtown, Warsaw and Kinston; between Belhaven and Swanquarter; over Lake Mattamuskeet; across Croaton Sound and the Oregon Inlet on the Outer Banks--all sparsely populated areas. Thus, pressure, wind, and rainfall conditions while the storm was inland must necessarily be based on sparse reports. Those reports

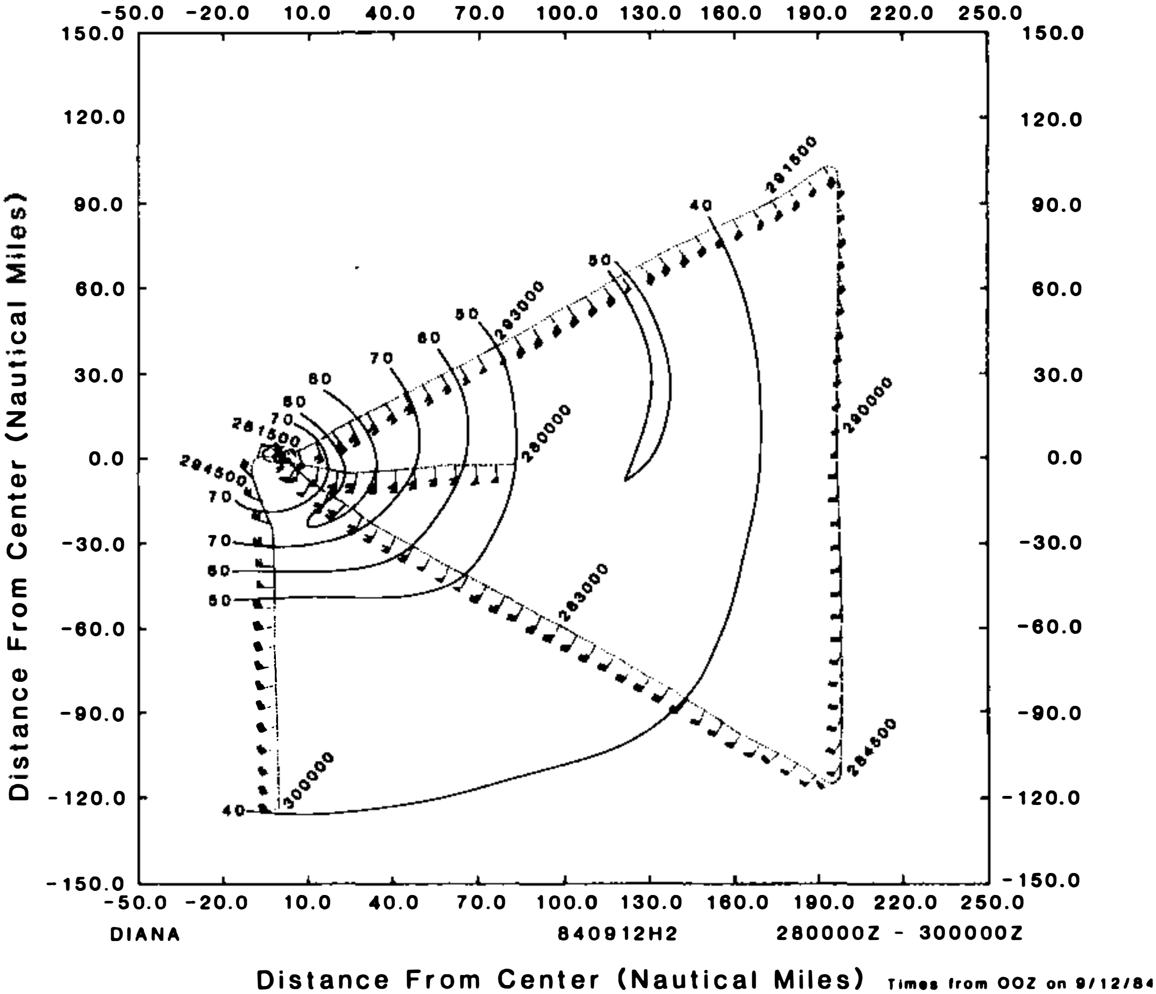


FIGURE 2.6 Winds of Hurricane Diana at 5,000 ft, September 12 (barbs and isolines of equal wind speed in knots). Short crossbars equal 5 knots; long crossbars equal 10 knots; and penants equal 50 knots.

indicate a marked decrease in wind speeds inland while storm winds persisted on the coast. Rainfall approached 14 inches in the Wilmington area with, again, marked reductions inland" (Gerrish, 1984). At the Brunswick Nuclear Power Station, there were 16 in. of rain.

One tornado occurred in Nash County in northeastern North Carolina (Lawrence and Clark, 1985). Several other tornadoes were reported, but poststorm investigations by National Weather Service meteorologists suggested that in most cases the damage patterns could be accounted for by winds typical of the hurricane's circulation.

TABLE 2.1 Wind Data from Hurricane Diana

Location	State	Date	Time	Sustained mph	Sustained kts	Gusts mph	Gusts kts
Vero Beach	FL	8	1656Z			30	26
Melbourne	FL	9	0000Z			32	28
Daytona Beach	FL	9	2145Z	25	22		
	FL	9	2329Z			35	30
St. Augustine Inlet	FL	10	0110Z	40	35	69	60
Jacksonville Beach	FL	10	0130Z	29	25	46	40
Jacksonville WSO	FL	9	1916Z	20	17	25	22
Savannah WSO	GA	9	2145Z	21	18	29	25
Tybee CGS	GA	10	2200Z	25	22	35	30
Charleston WSO	SC	11	1803Z	27	23		
Downtown Charleston	SC	11	2100Z	32	28		
Myrtle Beach AFB	SC	13	1420Z	37	32		
Crescent Beach FSS	SC	13	1550Z	45	39		
Florence FSS	SC	13	1149Z	18	16	30	26
Wilmington WSO	NC	13	0640Z	46	40	74	64
Oak Island CGS	NC	11	2345Z	115	100		
Norfolk Intl. Airport	VA	14	1957Z			38	33
Elizabeth City FSS	NC	14	1900Z			35	30
Cape Hatteras	NC	14	1350Z	32	28	45	39
Ft. Macon	NC	Unknown			35-58	30-50	
Diamond Shoals	NC	14	1200Z	45	39	64	56
Duck DARC	NC	15	0000Z	28	24	53	46
Ft. Fisher AFS	NC	12	0610Z	69-92	60-80	>115	>100
Shallotte	NC	13	0905Z	50-70	43-61		
Brunswick County	NC	13	1030Z			≤120	≤104
New Hanover County							
(One mile N. of	NC	13	0640Z	35	30	75	65
Ogden County Airport	NC	13	0653Z	44	38	74	64
Carolina Beach	NC	13	0345Z	86	75		
Holden Beach	NC	11	2250Z	70	61		
Wilmington CGS	NC	12	0610Z	>91	>79		
Wrightsville Beach	NC	13	0100Z	35	30	58	50
Kure Beach	NC	12	0423Z	69-81	60-70		
15 NW Beaufort (unoff.)	NC	Unknown				75	65
Supply	NC	11	2327Z	50-60	43-52		

TABLE 2.2 Minimum Pressure Data from Hurricane Diana

Location	State	Date	Time	in.	mb
Vero Beach	FL	9	0851Z	29.84	1011
Melbourne	FL	9	1000Z	29.83	1010
Daytona Beach	FL	10	0000Z	29.77	1008
Jacksonville WSO	FL	10	0948Z	29.78	1009
Savannah WSO	GA			29.83	1010
Charleston WSO	SC	11	0800Z	29.75	1008
Myrtle Beach AFB	SC	13		29.77	1008
Crescent Beach FSS	SC	13	1550Z	29.71	1006
Florence FSS	SC	11	1851Z	29.83	1010
Wilmington WSO	NC	12	0050Z	29.53	1000
Cape Hatteras	NC	14	1800Z	29.60	1002
Holden Beach	NC			29.56	1001
Suppey	NC			29.62	1003

Adequacy of Data

Diana was observed by "Hurricane Hunter" aircraft throughout most of its history. According to Lawrence and Clark (1985), "These aircraft penetrated into the storm center 50 times during a 111-hour period and this averages to one center position fix every 2.2 hours." The data in Figures 2.1 through 2.7 are partially--and, in some cases, entirely--based on measurements taken by these instrumented aircraft. Thus, both the interior of the storm and storm positions were well documented.

Radar coverage of Diana was also excellent. This applied both for airborne radar as well as for the coastal radar operated by the National Weather Service. The radar tracking of Diana strongly supplemented the tracking of the storm center by reconnaissance aircraft. Figures 2.2 and 2.7 give pictures of Diana as recorded by radar. These illustrate the changing structure of the storm and show how close it was to land from about noon on September 11 until it crossed the coast on September 13.

Deficiencies in data were most notable in the measuring and recording of winds and water levels along the coast during the period when conditions were worst; in measuring and recording rainfall at more places over land; and in obtaining wind measurements at upper levels needed for forecasting the hurricane's movements. More wind speeds near the surface were needed in the area where winds were strongest, namely along the coast, as Diana approached on September 11-12 and as it went inland on September 12-13. Only at the Brunswick Nuclear Power Station was there a well-calibrated anemometer connected to a recorder in the area where the strongest winds probably occurred. The next closest anemometer with a recorder was at the National Weather Service station

TABLE 2.3 Rainfall and Tide Data from Hurricane Diana

Location	State	Date	Rainfall (in.)					Tor-nadoes	Tides (ft above normal)
			1 hr	6 hr	12 hr	24 hr	Storm Total		
Daytona Beach	FL	9-10	0.40	1.21	1.90	2.57	2.70	0	2
Jacksonville WSO	FL		1.25	2.64	2.95	3.13	0		2.7
Savannah WSO	GA		0.21	0.34	0.36	0.36	0		2.5
Downtown Charleston	SC								1.1
Pee Dee	SC	13		0.69	1.39		1.39		
Dillon	SC	13-14				2.00	2.00		
Wilmington WSO	NC	11-14	1.03	4.93	6.49	7.51	13.72	0	5
Patrick Henry AP	VA						0.25		
Norfolk Intl. AP	VA						1.08		
Elizabeth City USCG	NC						3.72		
Cape Hatteras	NC	14	0.50	1.06	1.28	1.30	1.30	0	1
Ft. Macon	NC								4
New River	NC								2
Frisco Pier	NC								1.4
Oriental	NC								2
Lower Chesapeake Bay	VA								2
Myrtle Beach	SC								3-5

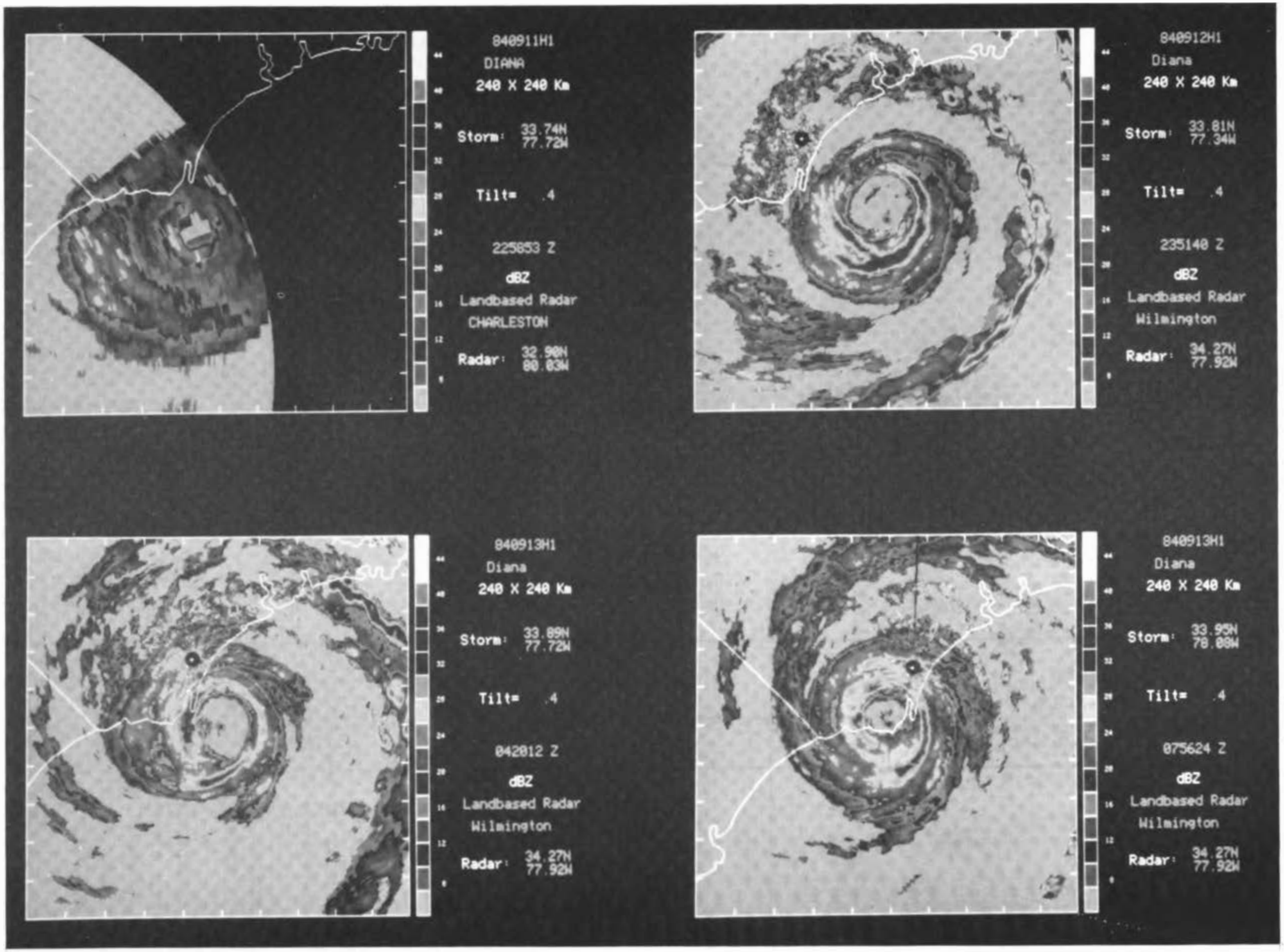


FIGURE 2.7 Radar imagery of Hurricane Diana, September 13.

at Wilmington, and the winds were definitely weaker so far inland. Along the outer islands where the winds were strongest, there were no well-located anemometers with recorders. The few reliable anemometers installed had to be read by observers who were withdrawn when conditions became dangerous.

Apart from the exceptions noted above, winds at various levels were measured quite adequately over land. Over the sea, at distances of 400 miles or more from the hurricane's center, the principal means of obtaining data on wind speeds at various levels was by tracking clouds using satellite imagery. While this information can be helpful, it is impractical to obtain the data by this means at all places where they are urgently needed. Experiments have been conducted to obtain wind speeds through the lower half of the atmosphere using dropwindsondes dispensed from aircraft. Results are encouraging, and perhaps in time this will make it possible to obtain the needed data (Burpee et al., 1984). Experiments are also being conducted to obtain the airflow at various levels using VAS satellite retrieval to prepare height contour maps of pressure levels in the middle and upper troposphere (Gentry, 1986). Until additional data are obtained by these or other means, forecasters will be handicapped in their efforts to make reliable forecasts of the direction and speed of forward motion of hurricanes.

There were some rain gauges, but in the thinly populated area that Diana traversed after moving inland there were too few for useful meteorological analysis.

Why Did Diana Weaken?

There are at least three reasons why the storm weakened on its slow clockwise loop.

First, cooler, dry air was most likely drawn into the hurricane's circulation. Hurricanes are heat engines, and their fuel comes from the warm, moist air that flows into their circulations. While the storm was looping offshore, it was always close to land, and the northern and western portions of its circulation extended over land (Figures 2.2 and 2.7). As noted earlier, a cold, dry airmass had passed over the south-eastern United States just before Diana developed. By September 12 this air had been modified considerably, but it was still cooler and drier than the air needed to maintain a hurricane at steady intensity. Wind reports from the surface to at least 5,000 ft appear to show that some cooler, drier air was being drawn into Diana's circulation at lower levels, especially during September 12. This is sufficient to account for the weakening that occurred.

Second, the sea surface beneath Diana was cooling. It has long been known that such temperatures need to be at least 26 degrees Celsius and should be higher for a storm to be very intense (Palmen, 1948). Sketchy measurements suggest that temperatures just to the south of the North Carolina capes, where the loop took place, were just above 26 degrees on September 11 but had fallen slightly by September 13. This frequently happens when a hurricane remains over the same body of water for a significant time. The stirring action of hurricane winds often brings colder water from depth to the surface. In addition, the hurricane draws off heat energy to nourish its circulation. Perhaps even more important, the loop made by Diana was entirely on the northern and landward sides of warm water associated with the Gulf Stream (Stephen Baig, National Hurricane Center, personal communication). Available information suggests that water temperatures here were colder than 26 degrees Celsius.

The third possible reason for Diana's weakening is harder to evaluate. During the time the storm was south of the Carolina capes, it frequently possessed two concentric eyewalls (Figure 2.7). Wind maxima were associated with both eyewalls, but the outer maximum was weaker. In such circumstances the inner eyewall often dissipates and its band of relative maximum wind speeds disappears. Sometimes when this happens, the outer eyewall and its associated wind maximum contracts. Following the principle of conservation of angular momentum, as the radius of maximum winds decreases, wind speeds increase. Sometimes the new inner maximum is higher than the previous inner maximum (Willoughby et al., 1982). It is not certain that this mechanism was operating when Diana approached the coast on September 12-13. But if it was, the immediate approach onshore would not have provided sufficient time for the outer eyewall to contract. At least in this case, the proximity of land would have kept the outer maximum from contracting and would have left the storm with the relatively weaker maximum at the greater radius.

Forecasting Success

The forecasts issued for Hurricane Diana were more accurate than those normally issued for storms passing through the same area. The mean error is defined as the difference between the forecasted (24 hour) position and the actual storm position one day later. During the 1970s, it was over 140 miles for storms near to the south and east of Cape Hatteras (Newmann and Pelissier, 1981a). For Diana, it was 93 miles--a considerable reduction.

Criteria for rating the difficulty of forecasts have also been developed by Neumann and Pelissier (1981b). In essence, storms are more difficult to forecast when, like Diana, they are moving erratically, but forecast errors are usually smaller when storms move slowly. On this basis, Diana appears to have been easier to forecast than the average storm included in a 1970-79 period of analysis. Thus, forecast accuracy may have been close to state of the art. However, the significant reduction in average error of the official forecasts, compared to what had been previously accomplished for storms in the same area, suggests a better than state-of-the-art performance. This is a notable accomplishment because there was insufficient information about upper-air winds to the east of the hurricane's center.

The critical forecasts were made at relatively high latitudes for tropical cyclones, and Diana formed in a situation more characteristic of mid-latitude conditions than do many tropical cyclones. It is thus not surprising that the National Weather Service's dynamical models for mid-latitute forecasting performed well. Under such conditions they often perform better than the statistical-climatological models developed for forecasting hurricanes. In this case, however, the best performing technique for the critical time periods was the NHC-72, a statistical-synoptic forecasting technique (Neumann and Pelissier, 1981b). For the longer time periods, the dynamical models furnished more accurate forecasts.

Diana appears to have been handled very well from a meteorological standpoint. In fact, the success of the forecasters might give a false sense of security because, historically, the paths of looping, erratically moving storms have been very difficult to forecast accurately. Such storms may not be forecasted nearly so well in the future.

COASTAL PROCESSES

Introduction

Hurricane Diana would probably have resulted in less destruction than Hurricane Hazel even if the storms were of equal magnitude. Building codes were strengthened and upgraded in the wake of Hazel, so that new homes were elevated on pilings to clear storm tides, and a building setback line was enacted by the North Carolina Coastal Zone Management Program (Owens, 1983). However, ground inspections and aerial surveys showed that many buildings were located less than 100 ft from the water's edge, particularly in Wilmington Beach (Figure 1.2). These houses might have been destroyed or might have sustained significant wave damage if Hurricane Diana had come ashore during the high water levels on September 11 instead of a day later.

Storm Surge

As usually occurs in severe conditions, all open-coast tide gauges were destroyed by storm waves during Diana's passage. Fortunately, the tide gauge at Carolina Inlet Marina, opposite Carolina Beach inlet, operated throughout the storm. A plot of the observed storm tide compared with the predicted astronomical tide showed that the maximum storm surge was 5.5 ft (Figure 2.8). Hurricane Diana arrived on a falling tide, with the maximum storm surge occurring at 2:00 a.m. on September 13 when the water was near mean water level. The National Ocean Survey (NOS) tide gauge at Southport recorded a maximum water level of 5.9 ft above mean low water (MLW), or 4.2 ft above mean sea level (MSL), at 8:54 a.m. on September 13 (T. Jarrett, U.S. Army Corps of Engineers, personal communication).

The maximum height and landward penetration of the surge waters were marked by drift line deposits. A drift line composed of eelgrass and other debris was found around the City Hall in Carolina Beach after floodwaters overtopped a municipal dock. This building housed the police department and served as a Red Cross relief center. Dauphine and Canal streets were flooded by several feet of water during the peak surge, and drift material was found along the entrance to a Hardee's

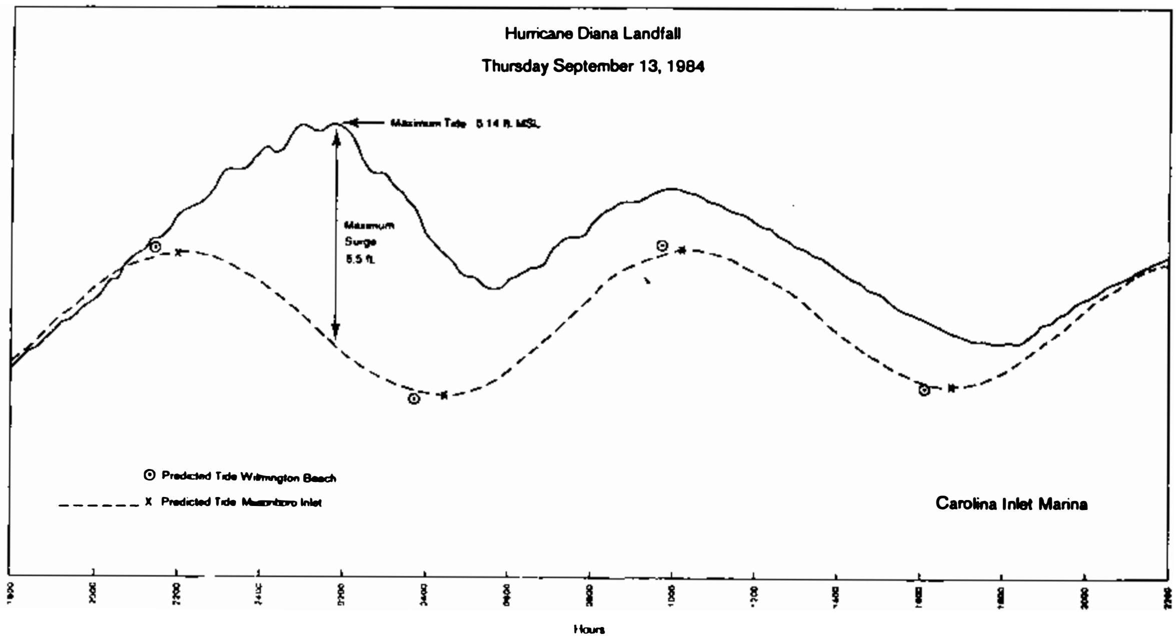


FIGURE 2.8 Observed and predicted storm tide at Carolina Inlet Marina, September 12-13.

parking lot (Figure 2.9). Based on a U.S. Geological Survey topographic map for Carolina Beach, and in the absence of benchmark data, the drift line appeared to lie beneath and parallel to the 5-ft contour line. It is estimated that the peak surge level was approximately 4.5 ft MSL.

There are two slightly different accounts of the storm surge level at Southport, near the mouth of the Cape Fear River. Site inspection by Robert Moul of the North Carolina Coastal Zone Management Program near Port Charley's Restaurant at Bay and Water streets indicated that the water barely crested the high marsh into the adjacent yard of the yacht basin. This suggests that the surge was little over 4 ft above MLW. According to Andy Garcia of the Coastal Engineering Research Center, U.S. Army Corps of Engineers, water level readings were taken by a resident who rode out the storm in his boat while docked at the Southport ferry landing. Based on measurements from the pilings, the peak storm tide was approximately 6.5 ft. Also, the debris line at Southport on the boat ramp of the marina was found to be 2.5 ft above high water (6.4 ft above MLW). This observation compares favorably with the Southport gauge measurement reported above (5.9 ft above MLW) and the Wilmington gauge (NOS), where the high water was 6.1 ft above MLW (Jarrett, personal communication).

Observations by U.S. Army Corps of Engineers personnel indicated that the storm surge to the west of Southport was minimal. The drift line was found to be below the Spartina patens high salt marsh on the

FIGURE 2.9 Storm surge drift line in Carolina Beach.

bayside of the barrier island, indicating that the storm waters did not reach spring high tide levels.

There was no real damage caused by the storm surge to buildings because of the relatively low maximum water levels during Hurricane Diana. This fortuitious situation was the result of a combination of a small storm surge and a falling astronomical tide.

The small surge generated by Hurricane Diana can be attributed to several factors. First, wind speeds decreased as Diana moved toward shore. Second, the radius of maximum winds was approximately 12 to 15 miles, so that the wind field was structured to produce waves arriving from the northeast rather than due east along the exposed beaches (e.g., Wrightsville Beach, Carolina Beach, Kure Beach). Since the waves and surge were directed more along the coast than straight onshore, there is much less damage than would be anticipated from a normally developed hurricane with a 20- to 30-mile radius of maximum winds. Third, the fetch was so short that extremely large waves and a high storm surge did not develop. Most of the surge seemed to have been due to the inverse barometer effect and wind set-up, with rainfall probably significant in enclosed water bodies. The Oak Island Coast Guard Station near Southport reported north to northwest (offshore) winds during the hurricane. Clearly, these winds would tend to lower the storm surge and reduce the waves along the coast west of Cape Fear.

Coastal Erosion

Ground and aerial surveys were made of the Cape Fear area, extending from western Long Beach in Brunswick County to Wrightsville Beach in New Hanover County (see Figure 1.2). Carolina Beach experienced the most severe conditions and sustained the greatest beach erosion compared with other areas.

The berm was completely removed, with a landward shoreline retreat of as much as 50 ft in some areas (Figure 2.10). The waves and resulting swash reached the dune toe in some areas, undermining the seaward extent of dune walk-over structures. An extensive lag layer of dark-colored heavy minerals was evident on the upper beach face, indicating significant erosion, with an estimated vertical cut of several feet (S. Benton, North Carolina Coastal Zone Management Program, personal communication). During the team's field surveys a subaqueous ridge was in the process of migrating onshore as a means of berm reconstruction. This observation of ridge and runnel development indicates the rapidity of beach recovery following storm activity.

Surveys of beach profiles were made at Carolina Beach after Hurricane Diana by the U.S. Army Corps of Engineers. According to Jarrett (unpublished data), nearly 200,000 yd^3 of sand were lost above the -2 ft MLW depth along a 10,000-ft stretch of shoreline. The shoreline retreated horizontally an estimated average of 45 ft. However, it is not clear how much of this erosion can be attributed to Hurricane Diana, since a small northeaster also influenced the area between the survey times. Also, the prestorm survey was completed four months prior to Diana (T. Jarrett, U.S. Army Corps of Engineers, personal communication).

The beaches west of Cape Fear were relatively unscathed, with only a foot-high beach scarp in the berm. The water never reached the dunes in this area, since the winds there during the storm peak were always along or off shore.

To the north of Carolina Beach lies Masonboro Island, an uninhabited barrier island (see Figure 1.2). This island experienced much overwash, since some crestal elevations are only 7 ft above MSL. Topsail Island was also subject to beach erosion and some overwash. This characteristically happens during northeast storms and spring high tides with a strong onshore wind. As was true with areas experiencing chronic beach erosion (e.g., portions of Fort Fisher Beach), two houses were lost at the southern end of Topsail Island. One house was undermined, and the other was completely washed away. Erosion tends to be quite severe adjacent to inlets, so these losses were no surprise. While the television media, in particular, and the press, in general, concentrated on these losses, they were not representative of average conditions along the shoreline.

The amount of coastal erosion was quite minor. The aftereffects of this storm were much less than those witnessed at West Galveston Island, Texas, following Hurricane Alicia (National Research Council, 1984) or Dauphin Island, Alabama, due to Hurricane Frederic. The storm effects of Hurricane Diana were similar in nature and extent to those generated by an average winter northeaster of several days' duration. However, as

FIGURE 2.10 Beach erosion permitting storm waves to reach revetment in Carolina Beach.

winter approached, the potential for severe erosion was high because the beaches were already narrowed to their high-energy profile configuration prior to the northeaster season.

3

BUILDINGS, STRUCTURES, AND LIFELINES

BUILDINGS AND STRUCTURES

Introduction

Hurricane Diana permitted observation of the performance of buildings and other structures under a particularly valuable set of circumstances.

1. Most of the area affected (i.e., North Carolina) is now subject to a residential building code that contains some of the most specific and stringent regulations regarding wind resistance used anywhere in the country. These regulations were introduced in the late 1950s after a series of hurricanes removed most of the substandard residential buildings then in existence. Subsequently, significant development has been subject to these new regulations.
2. Wind speeds approached, but are not thought to have exceeded, the design value. With conventional factors of safety, it is unlikely that there would have been significant damage to conforming structures.
3. Contrasting alignments of the impacted coastlines permitted observation of the effects of winds from a variety of directions and approach conditions. In addition, virtually all damage could be attributed to wind. Although hurricanes typically also inflict water damage, only wind effects are treated directly by most building codes.

It is conventional in damage surveys to classify all structures into groups according to the level of engineering effort involved in their design. These categories are (1) fully engineered, (2) preengineered, (3) marginally engineered, and (4) nonengineered. Fully engineered buildings and structures receive individual attention from professional architects and engineers (e.g., high-rise buildings, hospitals, and public buildings). Preengineered buildings and structures are engineered as a general structural system and marketed in similar units (e.g., manufactured housing, mobile homes, prefabricated construction, and metal buildings). Marginally engineered buildings and structures receive marginal engineering attention (e.g., motels, apartments, billboards, commercial buildings, and light industrial buildings). Nonengineered buildings and structures receive no specific engineering attention (e.g., most single- and multiple-family residences and small commercial buildings). As one moves through these classes, the responsibility for ensuring that the structure is able to withstand the forces prescribed by a building code passes progressively from design professionals to actual builders, who are often strongly influenced by tradition, prescriptive codes, and the efficiency of the building inspection process.

The majority of the buildings affected by Hurricane Diana were in categories 3 and 4. It proved fortunate that they were constructed primarily in an area of good building control.

Overview

Damage was observed from North Myrtle Beach, South Carolina, along the coast to Topsail Island, North Carolina, and inland as far as Shallotte and Wilmington, North Carolina (see Figure 1.2). The majority of the buildings affected were elevated single-family dwellings, but some damage was also done to mobile homes, motels, commercial premises, light industrial buildings, and apartment and condominium buildings. Most of this damage was concentrated between Long Beach and Carolina Beach.

Virtually all damage was a direct result of wind action. In extreme cases it resulted in the complete collapse of structures, but it was generally restricted to varying degrees of roof damage, often initiated by failure of porch support connections. Steep-pitched roofs usually performed better than low-pitched roofs, but one style of steep-pitched roof with large gable ends seemed very vulnerable to damage when the wind was blowing parallel to the ridge. Suction on the roof, coupled with pressure on the underside of overhangs, was the prime cause of damage. Suction on the walls of some buildings also created damage. In a few instances, direct pressure on the fronts of structures caused serious damage that was often exacerbated by loss of the diaphragm action of the roof.

Wave action caused some damage. Several fishing piers were seriously damaged, but this could generally be traced to poor construction. In one location, walling in the "breakaway" zone of a house below the lowest occupied floor was probably damaged by wave action. In another location there was sufficient undermining to cause a house to topple over. The following sections give a detailed description of the damage in each location together with a discussion of the building codes in effect in each area.

North Carolina

All construction in North Carolina is subject to the North Carolina State Building Code (North Carolina Building Code Council, 1978), which is a performance code that uses as its basis the Standard Building Code (Southern Building Code Congress International, 1982). One- and two-family dwellings may be constructed to the North Carolina Uniform Residential Building Code (North Carolina Building Code Council, 1968), a prescriptive code, the requirements of which are deemed to satisfy the provisions of the general building code. As a result of Hurricanes Hazel, Connie, Diane, and Ione in 1954 and 1955, specific recommendations were added to the code to ensure that walls provided sufficient shear resistance and that roofs were tied adequately to foundations.

Although the residential code has been mandatory throughout North Carolina since 1972, the provisions regarding wind resistance form an appendix, "Wind Resistive Construction," that is not mandatory but has been widely adopted in coastal areas. They are among the most stringent requirements in use anywhere in the United States and undoubtedly had a considerable bearing on the performance of structures in Hurricane Diana. Because of their importance, the general construction provisions of the appendix are reproduced in their entirety below. Details of the external sheeting to be used are given in the body of the code.

1. All structural roof members shall be directly over vertical supports to which they are tied.

2. Every other rafter shall be anchored to the ceiling joist and studs directly beneath by metal ties or timber framing anchors. In peaked rafters, opposite rafters shall be laterally braced to each other at the ridge by no less than the equivalent of 1" x 6" boards securely nailed forming a "Collar Beam."

3. At least every third rafter shall be anchored to the ceiling joist or partitions directly beneath by not less than the equivalent of a 1" x 6" board, securely nailed. Such braces shall be attached to the rafters at their midpoints or at the third points if two are used per rafter.

4. (a) For frame structures, every other rafter or truss shall be securely fastened to wood studs below with wind anchors. This includes outside walls and inside walls. The wood studs which are anchored to rafters or joist above must be anchored to beams or sills, and sills must be anchored to piles or other foundations. (b) One 3/8" steel rod every 8' (one shall be no more than 2' from each corner tieing rafters and ceiling joist all the way through wall and sill to foundation) can be used for tieing walls from top plate to foundation. (c) If diagonal wood sheathing ties top plate to bottom plate in a satisfactory manner, it would only be necessary to anchor rafters and joist to top plate and bottom plate to sill and sill to footing or piles. (d) Equal or better methods of tieing structures to foundations designed for a specific building by a registered Architect or Engineer may be acceptable by the Building Inspector.

5. For masonry buildings, the roof structure, including rafters and joist, shall be securely anchored to the footing by 3/8" steel rods not more than 8' apart, one of which shall be no more than 2' from each corner. All mortar used for masonry walls must be Type M, which is one part Portland Cement, 1/4 part hydrated lime or lime putty and not over 3 parts aggregate; this is frequently called Portland Cement Mortar.

6. All girders and large beams into which smaller joists are framed which bear on masonry foundation walls or piers shall be

anchored to the footing with 5/8" steel rods embedded at least 6" therein.

7. Where wood partitions and masonry walls join, the stud abutting the masonry shall be double and bolted to the masonry with three 1/2" galvanized bolts, one to be embedded in the tie beam, one in the mid-section and one near the base. The end of the partition plate shall also be anchored to the stud abutting the wall and to the wall plates.

8. Steel and wooden columns and posts, including porch columns, shall be anchored with metal ties and bolts to their foundations and to the members which they support.

9. For additional strength, where wood sheathing is used, it is recommended that such walls and roof sheathing be diagonal.

Figure 3.1 shows an example of a building being constructed in accordance with the above requirements.

Coastal areas affected by the storm include islands in Brunswick County and New Hanover County. The Brunswick islands run east-west, so most oceanfront property faces north-south. The New Hanover islands run approximately north-south, with most property facing east-west. Although much of the region was subjected to high winds on Diana's first approach to shore, most damage appears to have occurred during the second passage on September 12-13. Damage did not necessarily correlate with the highest wind speeds. Often neighboring structures or even the same structure showed damage from opposing wind directions, usually associated with a weakness such as a porch. Most damage on the Brunswick islands appears to have taken place when the winds came either from the land (north) or from the ocean (south). In New Hanover County, damage from northerly, easterly, and southerly winds was observed. Virtually all damage to residential structures occurred in those that either predated the residential building code or contravened the code requirements.

Brunswick County

Most of the development in Brunswick County consists of single-family dwellings. There are a few small motels and a few recently constructed condominiums but none exceeding four stories in height, including an unoccupied first story required for flood protection.

<u>Sunset Beach</u> Damage appears to have been restricted to loss of a roof in an old building near the center of town.

<u>Ocean Isle Beach</u> A flat-roofed masonry building associated with the bridge to the island lost its complete roof and the top layer of masonry blocks. The walls were unreinforced, and the roof was connected in the usual way with grouted anchors (Figure 3.2). Several inadequately tied porches had been removed, sometimes with parts of adjacent roofs.

FIGURE 3.1 Typical coastal construction, North Carolina.

FIGURE 3.2 Roof failure of masonry building, Ocean Isle Beach.

Holden Beach Several poorly anchored travel trailers were overturned (Figure 3.3). One house lost its roof entirely (Figure 3.4), and several near the east end of the island lost porches and parts of their roofs. The house shown in Figure 3.5 is typical of several that, although they had steep-pitched roofs normally considered to possess good wind resistance, suffered serious damage when the wind was parallel to the roof. The susceptibility of this type of roof to damage from wind from this direction was recently noted in wind tunnel tests by Hessig (1986). The east end of the island has suffered serious erosion in the past, and several houses are very close to the sea. In one, the part of the house intended to break away to relieve flood and wave forces appeared to have been damaged by waves.

Long Beach During Hurricane Hazel, 352 of the 357 homes in Long Beach were destroyed. Some rebuilding appeared to have taken place prior to the adoption and enforcement of the more stringent residential building code. Again, there was a considerable amount of porch and roof damage to private housing (Figure 3.6), small multiple-family dwellings (Figure 3.7), and the Long Beach Motel (Figure 3.8). A poorly braced condominium under construction adjacent to the motel collapsed. One form of design shown in Figure 3.9 seemed particularly vulnerable. Six examples of this type of construction suffered severe porch damage. Three houses that probably predated the building code lost complete roofs due to poor connection to the walls. The house shown in Figure 3.10 had lost most of its roof when the wind came from the land. It lost the rest when the wind came from the sea. This was not the first time the house had lost its roof, but it still had very poor connections between the roof and the walls (Figure 3.11). One new house also lost its complete roof (Figure 3.12). The beams had been tied to the frame, but the rafters had only a light nailing connection to the beams (Figure 3.13).

Away from the beach, a masonry garage of poor construction collapsed completely and the joint police-fire department building lost a considerable amount of siding. It was subsequently declared unsafe.

Yaupon Beach This small community on Oak Island, between Long Beach and Caswell Beach, has only a small amount of waterfront property. Most housing is well sheltered by trees. No obvious structural damage was observed.

Caswell Beach Situated at the east end of Oak Island, Caswell Beach probably experienced the highest winds in Brunswick County, but most of the structures performed well. Porches again initiated some roof failure. Poorly secured eaves on a steep-pitched roof, coupled with inadequate roof nailing, also caused a roof failure in a location affected by both northerly and southerly winds (Figure 3.14).

A condominium building lost some of its siding in an area of high suction between it and an adjacent building. The building also showed

FIGURE 3.3 Overturned travel trailers, Holden Beach.

FIGURE 3.4 Roof damage, Holden Beach.

FIGURE 3.5 Porch and roof damage to a steep-pitched roof, Holden Beach.

FIGURE 3.6 Porch and roof damage, Long Beach.

FIGURE 3.7   Apartment damage, Long Beach.

FIGURE 3.8   Porch failure at the Long Beach Motel.

FIGURE 3.9 Typical weak porch construction, Long Beach.

FIGURE 3.10 The "Blue Haven," Long Beach.

FIGURE 3.11 Detail of poor roof connection, "Blue Haven," Long Beach.

FIGURE 3.12 Roof damage to recently constructed house, Long Beach.

FIGURE 3.13 Detail of roof connection in recently constructed house, Long Beach.

FIGURE 3.14 Eave and roof damage, Caswell Beach.

significant shingle damage on its low-pitched roof. The adjacent buildings with higher-pitched roofs appeared to have been untouched.

At the extreme eastern end of Oak Island is Fort Caswell, now used as a Baptist assembly ground. Many of the buildings were clearly old. One unused building suffered porch and roof damage (Figure 3.15), but a similar adjacent building remained virtually untouched (Figure 3.16). One masonry wall had collapsed from a northerly wind, but an overflight of the area indicated virtually no damage to the rest of the buildings, including tall brick chimneys. This suggests that the military required an extremely high standard of construction when the fort was constructed.

Southport Southport lies on the mainland opposite Fort Caswell. Initial reports indicated very severe damage to the town, but these proved to be greatly exaggerated. One homeowner, using an anemometer mounted 50 ft above the ground in a location exposed to southerly winds, reported wind speeds of 100 mph from the south-southwest for 5 minutes at about 4:50 a.m. on September 13. Nevertheless, damage in the town was generally restricted to minor roof damage. Some damage was caused by falling trees, but trees generally provided considerable shelter to the community. However, one steel-framed building in an exposed position lost some of its lightweight siding (Figure 3.17). Other preengineered buildings in the area using metal siding appeared to have escaped undamaged.

Bald Head Island This is an exclusive community on an island in the mouth of the Cape Fear River with no bridge connections to the mainland. An overflight of the island indicated only minor roof damage, but no detailed inspection was made.

Inland Locations Although wind speeds apparently dropped rapidly away from the coast, a number of examples of damage were observed inland. In Grouse Landing, about 1 mile from the open sea, a poorly constructed house lost its roof and part of its upper story (Figure 3.18). Little structural damage was seen nearby, but a line of tree damage was observed. It is possible that an isolated tornado touched down in the area. About another mile inland a mobile home--apparently well tied down--lost its roof to northerly winds (Figure 3.19).

In the town of Shallotte, about 5 miles from the ocean, sustained wind speeds between 50 and 70 mph were reported on September 13. Some sign and canopy damage was observed in the town, and a shopping center under construction on the outskirts was damaged. The shopping center's structural system consisted of a light metal deck roof supported by truss rafters bearing on internal columns or external masonry walls. At the time of the storm the walls were up and the roof completed for all stores except one on the northern end. Here the walls had been completed, including the bond beams, but the roof had yet to be assembled. The walls thus stood over 20 ft high and were free standing. The front

FIGURE 3.15 Porch damage to old military building, Fort Caswell.

FIGURE 3.16 Undamaged military building, Fort Caswell.

FIGURE 3.17 Damage to preengineered building, Southport.

FIGURE 3.18 Severe building damage, Grouse Landing.

wall consisted of 8-in. hollow concrete masonry units with 4-in. facing stone. The other walls were made of 12-in. hollow concrete masonry units. None of the walls contained vertical reinforcement. The side wall collapsed inward, the front wall outward (Figure 3.20). These walls were of a design that would not have been capable of carrying the wind loads specified by the North Carolina Building Code even if they had been supported by the roof. Unfortunately, similar walls and very light roof systems are often relied upon to provide stability for this type of structure. Their failure during a tornado in a similar shopping center in Bennettsville, South Carolina, precipitated the complete collapse of a large department store (National Research Council, 1985).

New Hanover County

Fort Fisher The North Carolina Marine Resources Center, an engineered reinforced concrete building, suffered only minor flashing damage on the roof. An anemometer on the roof recorded a peak wind speed of 92 mph. A military base at Fort Fisher contains two large radomes (Figure 3.21). These and most of the base appeared to have been undamaged. Recent wood-framed condominium developments in the area were also undamaged.

Kure Beach The major damage in this small community occurred to a motel that lost its roof from a southerly wind. The failure was initiated by a poorly connected porch. Debris from the roof did considerable damage to the roof of an adjacent building (Figure 3.22). The motel, built about 1965, had tie-down clips, but they were improperly installed (Figure 3.23). Two houses suffered roof failures, and an unreinforced hollow concrete masonry building experienced roof and wall failure (Figure 3.24). Two sections of the 800-ft-long Kure Pier were washed away.

Wilmington Beach Several houses lost porches due to poor construction, and three mobile homes were severely damaged. A motel built about 1960 of reinforced masonry lost its flat roof (Figure 3.25). The roof had been toe-nailed into a wooden top plate. The reinforcing bars had been bent over the rafters. These had been pulled straight and the nails pulled out. To the rear of the motel, another roof failed. This had fairly good tiedowns, but the roof still pulled out of the bolts. Another masonry house also lost its roof; in this case, the hold-down bolts appeared to be too widely spaced and did not have washers.

Carolina Beach Carolina Beach was probably the most seriously damaged community. It consists of a variety of buildings: domestic dwellings, some predating Hurricane Hazel; motels postdating most of the destructive hurricanes but probably predating the more stringent building code;

FIGURE 3.19 Loss of mobile home roof near Grouse Landing.

FIGURE 3.20 Failure of masonry wall in a shopping center under construction, Shallotte.

FIGURE 3.21 Undamaged radomes, Fort Fisher.

FIGURE 3.22 Motel damage, Wilmington Beach.

FIGURE 3.23 Incorrect use of hurricane anchors in a motel porch.

FIGURE 3.24 Loss of poorly anchored roof in a masonry building, Kure Beach.

modern three- and four-story condominiums; a variety of commercial buildings; and one five-story reinforced concrete building still being built at the time of the storm but structurally complete. This building lost a considerable part of its roofing membrane in an area likely to be in high suction during an easterly wind.

Several of the motels near the center of town lost their roofs, usually from easterly winds. The debris then inflicted considerable damage on buildings downwind. In one case a porch and roof were severely damaged by debris from a motel 800 ft away (in the foreground of Figure 3.26). Several wood-framed condominiums under construction collapsed. Some were merely unsupported frames, but two, located near each other and virtually complete, suffered shear failures due to a northerly wind. One lacked the interior drywalling, but the rest of the structure, including the exterior siding and the rods tying the roof to the foundations, had been completed. The third story failed in shear, and the fourth story, braced by the roof, was displaced sideways and collapsed onto the second story. The wall ties held and probably prevented complete collapse (Figure 3.27). The second building was at a similar stage of completion except that the tie-down rods had not been connected. This building collapsed completely (Figure 3.28).

A subsequent structural analysis and wind tunnel test (Readling, 1986) showed that even without tie-down rods the roof of the structure was unlikely to have failed at wind speeds experienced in Diana. However, even if the internal walls had gypsum wallboard, shear failure of the type observed could have occurred. The survival of similar completed structures nearby (Figure 3.29) was probably the result of adequate shelter rather than an adequate structural system.

One weakness common to these buildings was that the walls perpendicular to the long faces, which should have acted as shear walls, had large openings for patio doors. In order to survive the local design wind speed with an adequate factor of safety, most internal cross walls would have to be reinforced with plywood.

At the north end of Carolina Beach, several other condominiums suffered damage to siding and loss of shingles (Figure 3.30). The add-on eaves of several modular homes also flipped up. In the same area a 12-sided house was completely destroyed (Figure 3.31). Although rods had been used to attach the walls to the pile-framing, the exterior siding of the building had not been continued over the horizontal support beam. No details of the roof construction could be determined. This building was in the middle of a subdivision containing a variety of forms of construction that, with the exception of this building, suffered only minor damage. Insufficient consideration had obviously been given to details in the construction, but the basic shape of the building, lacking intersecting shear walls, may have contributed to its weakness.

In the center of the town, a modern seafood restaurant lost a considerable portion of its roof from an easterly wind, even though it was several blocks from the beach and should have received some shelter (Figure 3.32). Although the rafters were tied to the walls, it had a bi-pitched roof and the upper section appeared to have been poorly connected to the rest of the roof.

FIGURE 3.25 Roof damage to a masonry motel, Wilmington Beach.

FIGURE 3.26 Motel roof failure and debris damage, Carolina Beach.

FIGURE 3.27 Shear failure of a condominium building, Carolina Beach.

FIGURE 3.28 Collapse of condominium building, Carolina Beach.

FIGURE 3.29 Undamaged condominium, Carolina Beach.

FIGURE 3.30 Gable-end failure in a condominium building, Carolina Beach.

FIGURE 3.31 Complete failure of 12-sided building, Carolina Beach.

FIGURE 3.32 Restaurant roof failure, Carolina Beach.

Wilmington Most of the damage in Wilmington appeared to have been to trees. In one exposed area to the east of the town, several signs were damaged and a two-story motel lost its waterproof membrane. This resulted in considerable water damage to both stories of the motel. A very tall Exxon sign near the center of the city developed an alarming list owing to a failure at a point where a column changed diameter (Figures 3.33 and 3.34). Had the sign actually collapsed, serious damage and loss of life could have resulted. Considering the lack of other damage in that area of Wilmington, such a failure indicates a structure incapable of carrying loads well below the design level.

Wrightsville Beach and Other Locations These communities were not surveyed in detail, but it is believed that damage to structures was slight.

South Carolina

In recent years, the "Grand Strand" area of South Carolina's northern coast has developed rapidly. Most of the oceanfront between Myrtle Beach and North Myrtle Beach consists of multistory hotels or condominiums. Although there is no statewide building code in South Carolina, individual jurisdictions may adopt the Standard Building Code. Myrtle Beach and North Myrtle Beach have adopted this code.

This area was seriously damaged by Hurricane Hazel, but perhaps because the state was not subjected to the series of hurricanes that affected North Carolina in the following years, no serious attempt was made to emulate North Carolina's tighter control of construction by ensuring adequate wind resistance regulations. Most of the construction on the Grand Strand postdates Hurricane Hazel (1954) and thus had never been tested by hurricane-force winds. Many of the occupants of the area had also never before experienced a hurricane.

Although the area was evacuated on Diana's first passage, no damage was reported. When the hurricane turned west, an attempt was made to evacuate again but had to be restricted to the oceanfront streets in the northern section of the beach. Damage was reported only in the town of North Myrtle Beach, where wind speeds were thought to have reached 50 to 60 mph. Three houses suffered porch damage, and the eight-story Xanadu II condominium had a significant part of its cladding removed in the areas of highest suction. (Figure 3.35). Although the building had a strong concrete frame, the cladding system consisted only of an interior layer of drywalling, a metal stud frame with fiberboard screwed to it, a layer of Styrofoam insulation glued to the fiberboard, and a waterproof coat applied directly to the Styrofoam. The building had been completed about six months prior to the storm and should have been subject to the Standard Building Code, yet the cladding system apparently failed at a wind speed of less than half the design speed. Several other buildings using this form of cladding were observed under construction farther south. None apparently suffered any damage, but all were subjected to much lower wind speeds.

FIGURE 3.33 Sign damage, Wilmington.

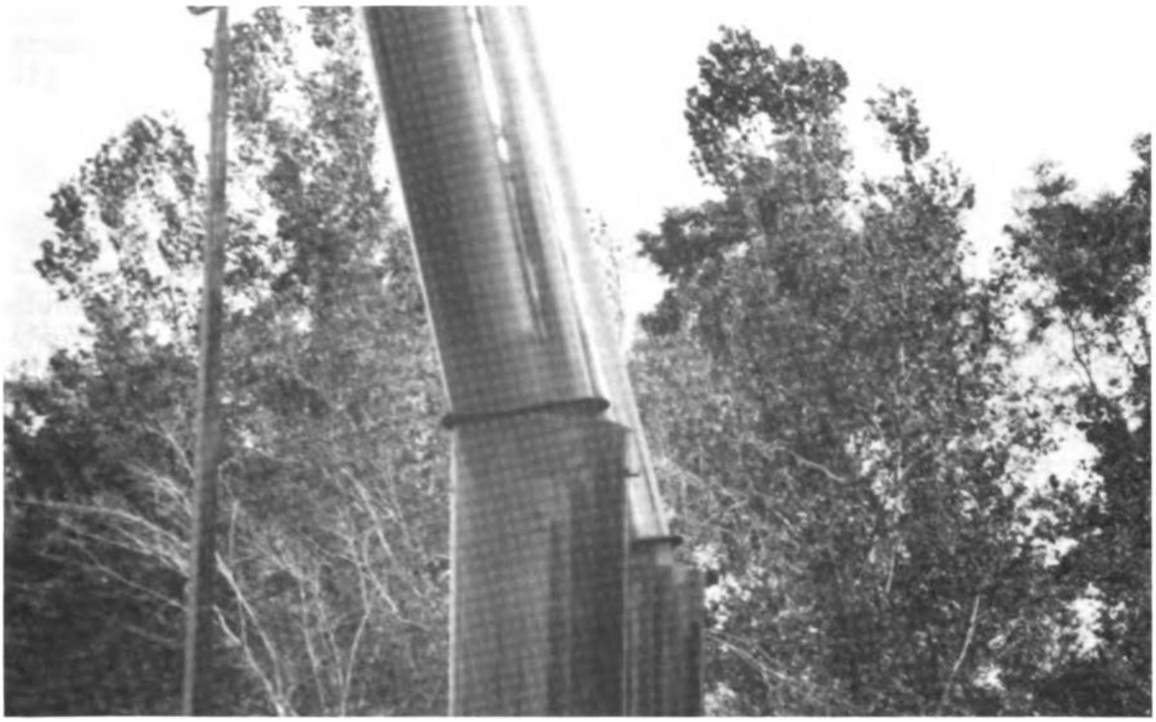


FIGURE 3.34 Sign joint detail, Wilmington.

FIGURE 3.35 Cladding failure, North Myrtle Beach.

LIFELINES

Power Stations

Carolina Power and Light Company's coal-fired Sutton generating plant reported no damage during the hurricane. Light damage occurred at the Brunswick Nuclear Power Station, but only to outbuildings. Neither nuclear generator was operating during Diana. One unit was in scheduled shutdown, and the other was automatically shut down on Monday, September 10, when lightning struck plant property, causing fluctuations in instrument control circuits. Diana's imminent arrival extended the shutdown because it was feared that the hurricane might damage power transmission lines. The buildings that house the reactors were designed to withstand winds up to 130 mph at ground level. Anemometers at the site recorded sustained winds of 75 mph, with gusts to near 100 mph. One mobile home within the plant's boundaries was blown off its foundations and destroyed.

Power Lines

Most power-related problems were caused by downed main distribution lines, power poles, and hookup wires to individual homes and by damaged small cables.

Power failures caused by high winds occurred in two overlapping waves that coincided with the first and second passages of Hurricane Diana (see Table 4.10). They began in some parts of Brunswick County around 4:00 p.m., Tuesday, September 11, and gradually spread throughout the Cape Fear region, including the city of Wilmington. Within a short period, 20 of Carolina Power and Light Company's 45 primary electricity feeder lines were disrupted by downed trees and fallen poles. All but 8 had been repaired by the time Diana finally came ashore on Thursday. Eleven of 12 feeder lines serving the Whiteville area in Columbus County also were out of service at some time during the storm. Downed lines left entire towns like Long Beach without electricity for three to six days. The most concentrated severe damage to power lines occurred in Carolina Beach and Kure Beach, where many areas were without electricity until Friday, September 14.

Loss of power created a variety of problems. Most suburban and rural residents were deprived of fresh water supplies because wells ceased to be pumped. In one town the municipal water tower was drained by Friday, September 14, and a portable generator was used to power pumps. Wilmington's Vision Cable (television) company also reported problems, but only 3 percent of cable television lines were damaged. The most discernible impact of electricity outages were vehicular backups around inoperable or damaged traffic signals at road intersections and railroad crossings. Most businesses throughout New Hanover, Brunswick, Pender, and Onslow counties closed on Wednesday, September 12, although many grocery stores remained open late.

Telephone Lines

Most problems with telephone service were caused by high wind, fallen trees, and downed poles and wires leading to houses (Figure 3.36). Total loss of service was confined to small areas in New Hanover and Brunswick counties. The fact that many Southern Bell lines were laid underground reduced the scale of damage. The most frequently cited problems were sluggish and sporadic service because of overloaded exchanges and circuits. No major problems were reported in Columbus and Bladen counties.

Radio and Television Stations

Just before 2:00 a.m. on Thursday, September 13, widespread power failures knocked Wilmington's television and radio stations off the

FIGURE 3.36 Downed telephone poles in Wrightsville Beach. The top of another pole hangs by a strand on the right. Photograph courtesy of Wilmington Morning Star, September 13, 1984; staff photograph by Gray Honeycutt.

air. At least two television stations (WWAY and WECT) kept running on emergency generators, but WECT operated at minimal power without telephones and with only the control room and studio functioning. It continued to run normal network programming with half-hour weather updates. The staff at WWAY struggled against a leaking roof and fears that the transmission tower would collapse on the studio. The station managed to broadcast hurricane reports continuously from 12:30 a.m. on Thursday, September 13, to 8:00 a.m. that morning.

All but one of Wilmington's radio stations were knocked off the air. For people who had access to battery-powered radio sets, WAAV was the region's sole source of news.

Airport Facilities

No damage was reported at the New Hanover County (Wilmington) Airport, the region's major civil aviation facility. Brunswick County Airport, on the mainland near Yaupon Beach, suffered major damage. The airport office, housed in a mobile home that had been securely tied down, did not overturn but received serious wall and roof damage (Figures 3.37 and 3.38). The new terminal building remained on cinder blocks but lost one end to wind damage. A total of four small planes were damaged by wind and by the collapse of a hangar (Figure 3.39).

FIGURE 3.37 Brunswick County Airport Office.

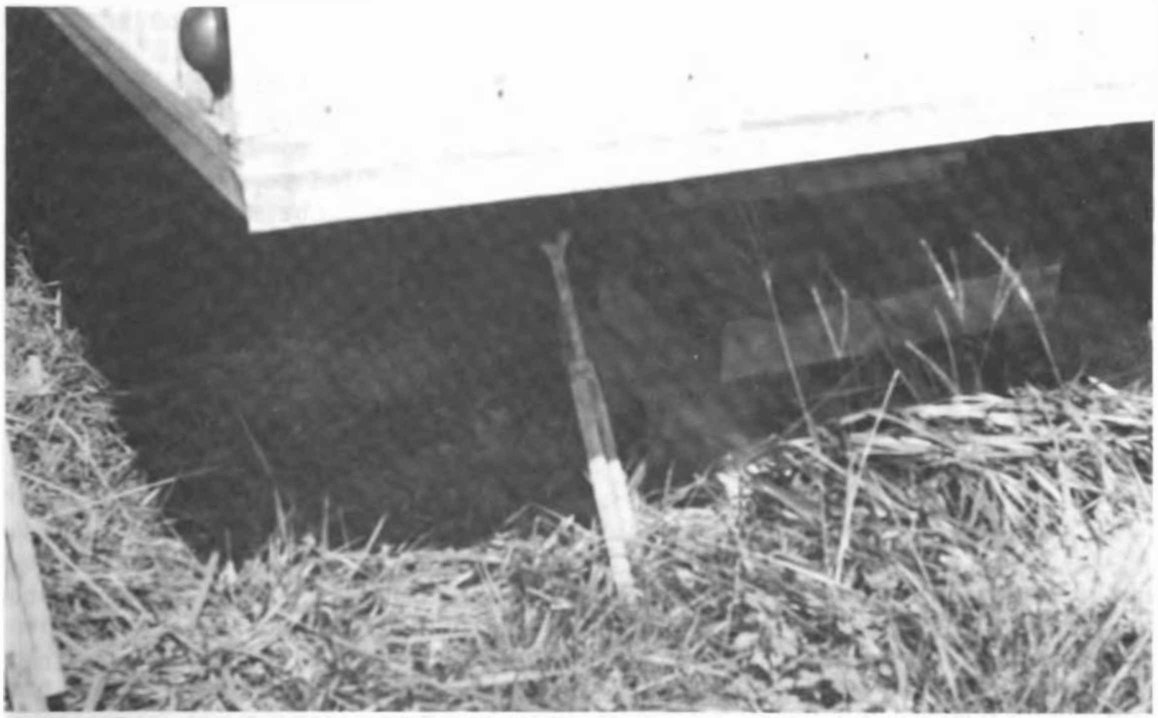


FIGURE 3.38 Typical tie-down at the Brunswick County Airport Office.

FIGURE 3.39 Brunswick County Airport hangar.

Roads and Bridges

Several streets in Carolina Beach were closed because of combined ocean and rainwater flooding on Thursday, September 13. They remained impassable for up to two days. Ocean floodwaters and sand blocked other streets in Holden Beach, Kure Beach, and N.C. 210 on Topsail Island. Many roads in Brunswick County were littered with debris and tree limbs or were partially flooded. Bridges to Sunset Beach, Oak Island, and Holden Beach were either temporarily closed because of rising winds and water or suffered slight to moderate wind damage.

Nontheless, Diana's impact on roads and bridges was relatively small. Perhaps the most significant disruption was the threatened closure of N.C. 87 and an adjacent railroad line because of a dam break at Boiling Springs Lakes (discussed below).

Water and Sewer Systems

The most spectacular failure of an engineered lifeline structure was the collapse of a 120-ft-high water tower containing 100,000 gallons of water. This tower had been built in Carolina Beach during 1934 by the Chicago Bridge and Iron Company and had survived several hurricanes. Figure 3.40 shows a tower of similar design located in South Carolina. An eyewitness reported that the failure occurred at approximately

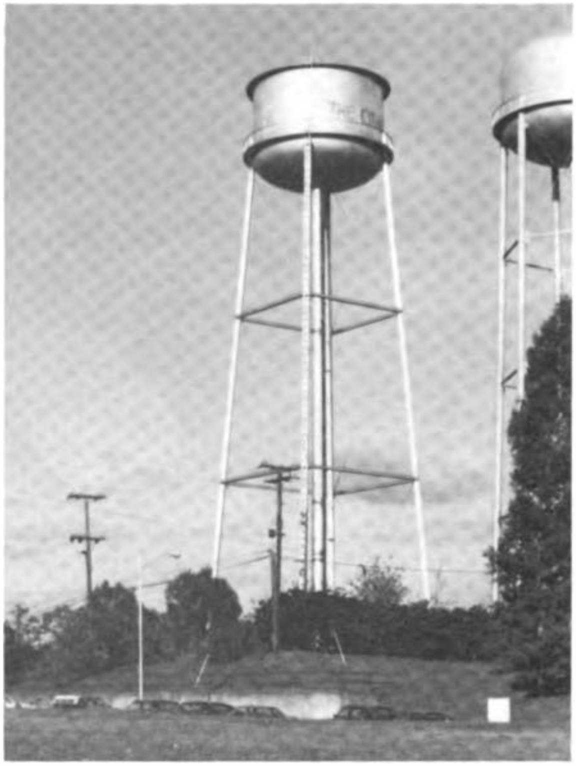


FIGURE 3.40 Water tower of similar design to the one that collapsed.

12:30-1:00 a.m. on Thursday, September 13, when the wind was from the north. The witness said that the tank appeared to rise slightly and then the tower collapsed more or less in place (Figure 3.41). As the tank hit the ground, it burst. The ensuing flood struck and burst open the back door of an adjacent library, demolished a pump house, and knocked a large hole in the wall of a control building.

Such a collapse would require the failure in tension of the holding bolt of a windward leg and the subsequent overloading and buckling of the remaining legs. Site investigation of the collapsed tower indicated that it may have been subjected to wind-induced vortices and vibration and that the anchor bolts appear to have failed in tension. Calculations based on the original drawings of the tower indicated that, if the tank was full, it would require a wind speed--at the level of the tank--of between 150 mph and 180 mph to initiate this type of failure. These speeds are inconsistent with the minor damage observed in adjacent structures. There are, therefore, three possible explanations for the failure. First, the tank may not have been full even though officials believed it to be so. However, it must have contained a considerable weight of water to cause the observed water damage in the vicinity. A second possibility is that the upper levels of the tower were in fact subjected to very high wind speeds, perhaps caused by a tornado that did not touch the ground. Third, the tower may have experienced some form of resonant response to the wind, amplifying the effect of wind forces and introducing the possibility of fatique failure of the structural components.

FIGURE 3.41 The tangled remains of Carolina Beach's 50 year-old 100,000-gallon water tower, which fell Wednesday, September 12, 1984. Photograph courtesy of Wilmington Morning Star, Friday, September 14, 1984; staff photograph by Jack Upton.

Destruction of the tower was not as serious as it might have been because local officials were already preparing to build a new 500,000-gallon ground level tank before Diana struck.

Elsewhere, damage to sewer systems was generally confined to clogged pipes filled with sand, tree limbs, debris, and rubble. Some broken water pipes were reported.

Earth Dams and Road Embankments

Five earth dams and road embankments are located on the Boiling Spring Lakes in Brunswick County (Figure 3.42). High water deposited by Hurricane Diana caused Big Lake to overflow onto N.C. 87, and the drainage pipes at three of the five dams (1, 2, and 3 in Figure 3.42) were clogged by fallen branches, leaves, and debris so that the embankments were subjected to critical flow conditions and overtopping (Figure 3.43). Figure 3.44 shows a typical failure induced by the overtopping, in which a section of road atop dam 1 was washed out due to the loss of shear strength from seepage into the dam materials. Figure 3.45 shows a schematic illustration of the failure. Sandbags placed by the U. S. Army Corps of Engineers on September 13 and 14 kept the dams from totally collapsing (Figure 3.46).

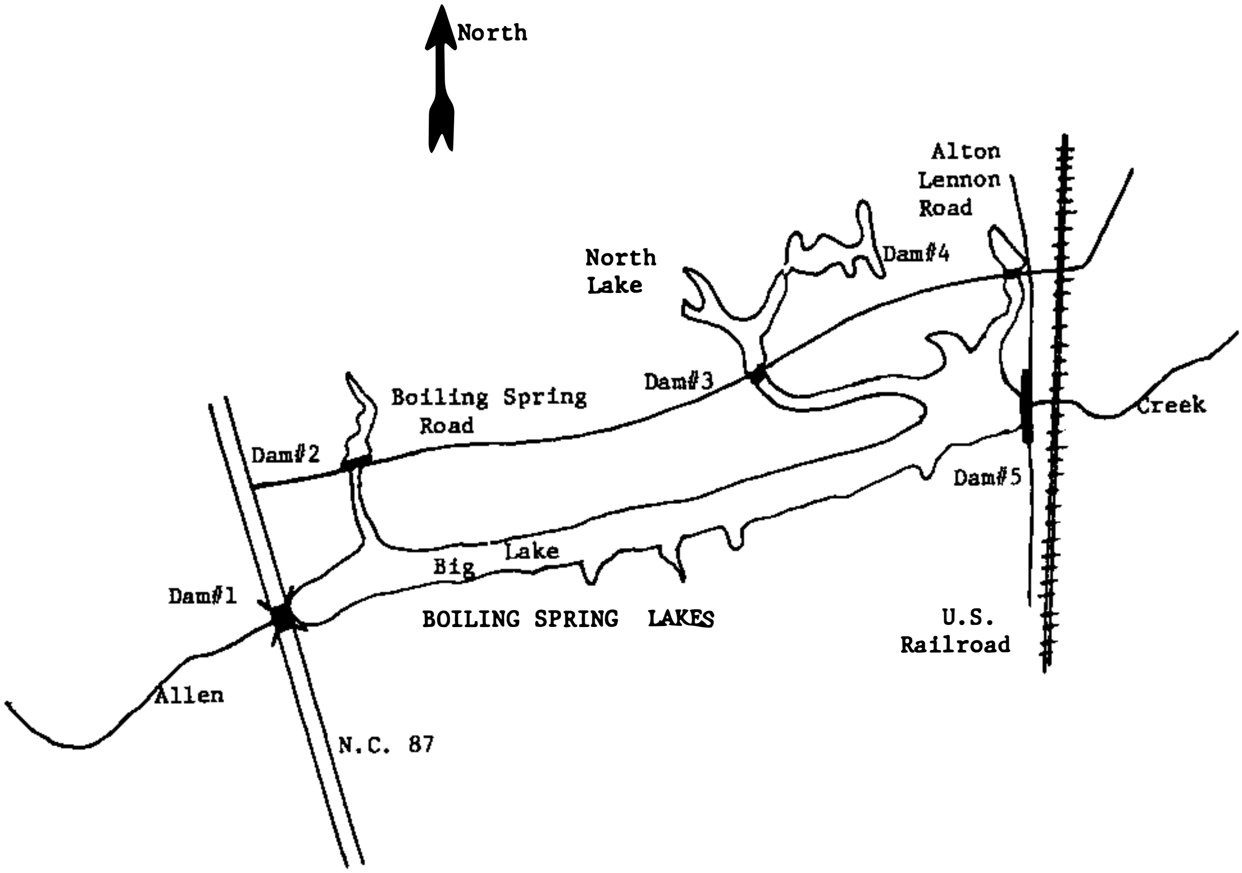


FIGURE 3.42 Earth dams and road embankments on Boiling Spring Lakes, Brunswick County, North Carolina.

The North Carolina Highway Patrol directed traffic through 3 ft of water on the adjacent two-lane road (N.C. 87). If the water had continued to rise in Big Lake, trouble would have developed at dam 5 (Alton Lennon Road), near the federal government's railroad line to the Sunny Point Army Terminal. North Lake, which flows into Big Lake, was also overflowing on Boiling Spring Road (3 in Figure 3.42). The Corps of Engineers sandbagged North Lake, slowing the flow of water into Big Lake and relieving pressure on the dam.

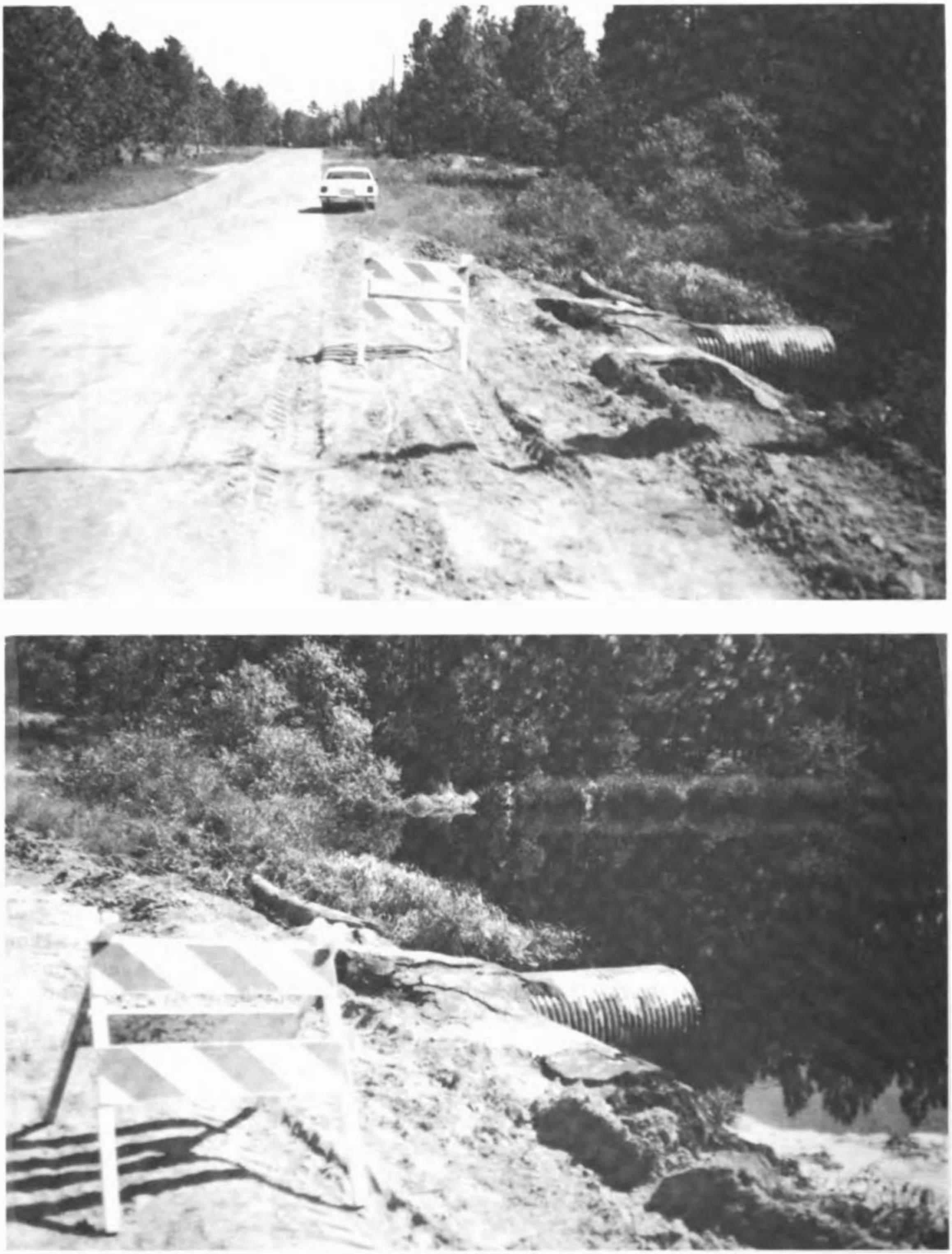
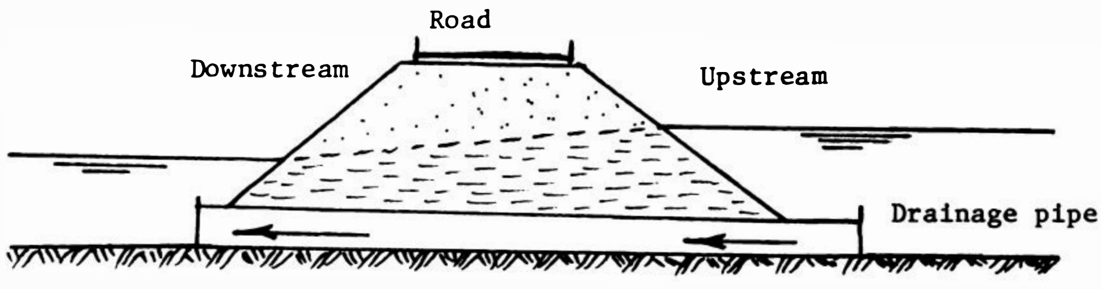
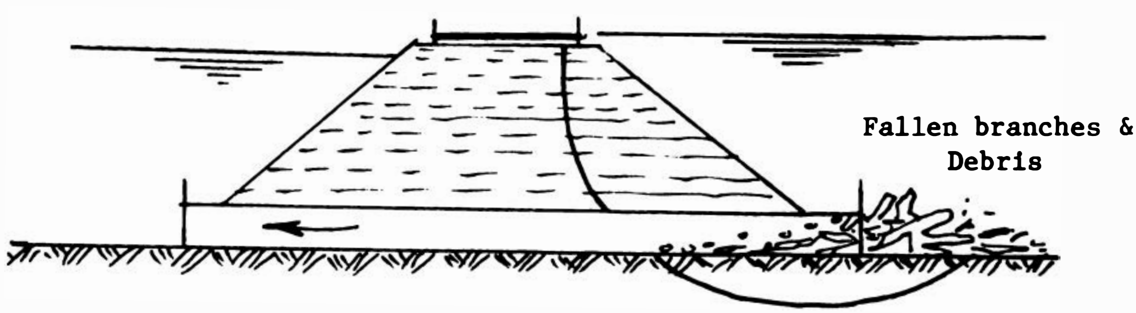


FIGURE 3.43 Drainage pipe of dam 3 on Boiling Spring Lakes clogged by fallen branches and debris.

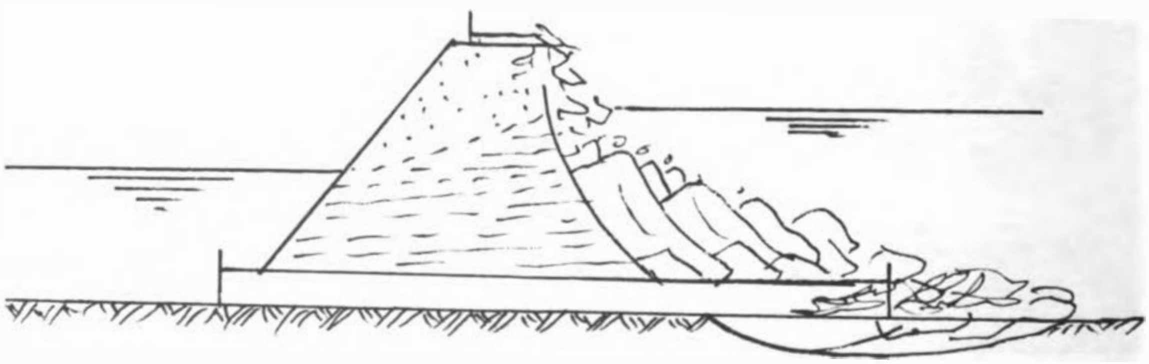
FIGURE 3.44 Part of dam 2 with partial stability failure.



a) Before the Storm



b) Overtopping caused by pipe clogging



c) A section of the Embankment washedout due to loss of shear strength of the saturated material.

FIGURE 3.45 Schematic diagram showing embankment failure induced by critical flow condition and overtopping.

FIGURE 3.46 Washed-out section of road atop a dam in Boiling Springs Lakes. Sandbags placed by the U.S. Army Corps of Engineers kept the dam and other dams from collapsing. Photograph courtesy of Wilmington Morning Star, Saturday, September 15, 1984; staff photograph by Dan Sears.

4

RESPONSE AND RECOVERY

EMERGENCY PREPAREDNESS IN NORTH CAROLINA

Previous Natural Disasters

During the past 30 years, major natural disasters have been declared on 14 occasions in North Carolina (Table 4.1). Most of these involved floods (six) and hurricanes (five). Prior to Diana, the most recent disaster was caused by tornadoes on March 30, 1984 (National Research Council, 1985).

Hurricanes and Other Coastal Storms

Hurricanes and other coastal storms are frequent and long-standing problems in North Carolina. Coastal districts of North Carolina are exposed to significant hurricane risks. On the southern flank of the Outer Banks, the annual probability of experiencing a hurricane strike is among the highest in the United States (11 percent), but farther south in New Hanover and Brunswick Counties the risk is considerably less (6 percent). The Cape Fear region possesses a hurricane risk similar to that faced by areas like Long Island, New York, southern New England, and the Tampa Bay region of Florida (Simpson and Lawrence, 1971).

In the period between 1900 and 1977, 31 hurricanes and 29 major extratropical storms affected maritime areas of North Carolina (Baker, 1978). The Cape Fear region last experienced significant hurricane losses from Hurricane Donna in September 1960, but Hurricane Hazel, which struck on October 15, 1954, is the storm of record for this area and much of eastern North Carolina. Its 140-mph winds and 14- to 15-ft storm surge killed 19 people and inflicted property losses in excess of $125 million. Every fishing pier in North Carolina was swept away. Four thousand homes and 1,000 other buildings were destroyed or severely damaged, including all but 5 of 357 homes on Long Beach Island, all 200 buildings at Holden Beach, all buildings in Ocean Isle Beach, and 475 buildings in Carolina Beach (McElyea et al., 1984, pp. 2-11 to 2-13).

From the standpoint of damage, Diana was a minor event compared with Hurricane Hazel. It was also less severe than several other storms that have affected North Carolina in the last 40 years (e.g., the hurricane

TABLE 4.1 Major Natural Disasters in North Carolina

Date of Disaster Declaration	Type	Federal Disaster Payments (thousands of dollars)[a]
Oct. 17, 1954	Hurricane Hazel	1,290
Aug. 13, 1955	Hurricanes Connie and Diane	5,254
Apr. 24, 1956	Severe storm	143
Oct. 1, 1958	Hurricane Helene and severe storm	846
Sept. 16, 1960	Hurricane Donna	1,209
Mar. 16, 1962	Severe storm, high tides, and floods	1,089
Oct. 13, 1964	Severe storm and floods	210
Feb. 10, 1968	Severe ice storm	290
Jun. 25, 1973	Severe storms and floods	378
Apr. 12, 1974	Tornadoes	215
Nov. 9, 1977	Severe storms and floods	18,085[b]
Sept. 29, 1979	Severe storms and floods	256
Mar. 30, 1984	Severe storms and tornadoes	7,917[b]
Sept. 21, 1984	Hurricane Diana	11,575[b]

[a]Does not include private insurance reimbursements and other non-federal funds. Unadjusted dollar totals.
[b]Disaster claims still open.

Source: L. Zensinger, Federal Emergency Management Agency, personal communication, 1984.

of September 14, 1944; Hurricane Ione in 1955; the Ash Wednesday northeaster of March 5-8, 1962). As measured by the level of federal disaster assistance payments, Diana is similar to relatively minor storms that have struck the United States, like Hurricane Belle and tropical storm Kathleen in 1976 (Table 4.2). It pales to insignificance in comparison with tropical storm Agnes in 1972, Hurricane Frederic in 1979, and Hurricane Alicia in 1980. However, Diana was a complex storm that frustrated forecasters and entailed major repeated evacuations of coastal populations from an area that has recently experienced rapid development (McElyea et al., 1984, p. 2-15)

The Region Affected

Hurricane Diana primarily affected two North Carolina counties with contrasting environmental and socioeconomic characteristics. Vulnerability to hurricanes is generally greater and evacuation potentially

TABLE 4.2 Federal Hurricane Disaster Assistance Payments

Date	Hurricane	State	Federal Payments (dollars)[a]
Aug. 4, 1970	Celia	TX	35,804,560
Oct. 13, 1971	Edith	LA	1,159,510
Jun. 23, 1972	Agnes	FL, NY, VA, PA, MD, WV, OH	498,671,255
Sept. 23, 1974	Carmen	LA	4,260,349
Sept. 3, 1976	Belle	NY	6,774,996[b]
Sept. 21, 1976	Kathleen	CA	8,506,580[b]
Sept. 13, 1979	Frederic	AL, MS, FL	234,277,493[b]
Aug. 11, 1980	Allen	TX	32,159,970[b]
Sept. 26, 1980	Danielle	TX	386,119
Nov. 27, 1982	Iwa	HI	15,328,940[b]
Aug. 19, 1983	Alicia	TX	46,217,102[b]
Sept. 24, 1984	Diana	NC	11,575,000[b]

[a]Does not include private sector and nonfederal payments. Unadjusted dollar tototals.
[b]Disaster claims still remain open.

Source: L. Zensinger, Federal Emergency Management Agency, personal communication, 1984.

more difficult in Brunswick County than in New Hanover County. This is because Brunswick County's barrier island elevations are somewhat lower, the east-west-trending shoreline lies across the predominantly south-north storm tracks, fewer and narrower roads connect islands with the mainland, and journeys to safe areas are longer.

New Hanover County is a small (185 square miles) urbanized area sandwiched between the Cape Fear River on the west and the north-south trending Atlantic oceanfront on the east (see Figure 1.2). Most of the county's 103,471 permanent residents live in unincorporated areas outside the river city of Wilmington (44,000) and the smaller coastal towns of Wrightsville Beach (2,786), Carolina Beach (2,067), and Kure Beach (546). Almost one fifth of the total population of North Carolina's 22 coastal counties is located in New Hanover County. Although Wilmington is a major urban center and the state's chief port, it is experiencing urban decay while major growth of service industries occurs beyond municipal limits.

All parts of the county's coastline are considered to be suffering critical erosion problems (U.S. Army Corps of Engineers, 1971). Mainland oceanfront areas are heavily developed, except in the extreme south (around Fort Fisher). Some barrier islands are heavily developed resorts (e.g., Wrightsville Beach, Carolina Beach), but others are occupied by high-priced, low-density residential tracts (e.g., Figure Eight Island) or remain entirely unpopulated (e.g., Masonboro Island). Approximately 20,000 temporary residents are typically in Wrightsville Beach at mid-summer, and the seasonal population of Carolina Beach varies from 30,000 to 40,000.

Brunswick County is a relatively large (861 square miles), lightly populated (35,777), but rapidly growing area that lies between the Cape Fear River and the South Carolina state line (see Figure 1.2). Much of the county is occupied by agricultural land and forests. The only significant urban center is Southport (2,824), near which is located a large nuclear power station. Brunswick County's coastline is entirely fringed by increasingly heavily developed and eroding barrier islands, some without road access to the mainland. The combination of generally low elevations and an east-west coastal alignment exposes the county to major risks from hurricanes that sweep up the Atlantic coast. During peak holiday periods, up to 75,000 additional seasonal residents may be present in coastal communities of Brunswick County.

Hurricane Preparedness

In September 1984, community leaders and most long-term residents of the coastal regions of North Carolina had a high level of awareness about hurricanes. It was nourished by several sources of concern. First was the disastrous experience of Hurricane Hazel in 1954. Second was the knowledge that 24 years had elapsed since the last major damaging hurricane had come ashore (Hurricane Donna in 1960). In that time a new generation of coastal dwellers, with little experience of hurricanes, had taken up residence (Herbert and Taylor, 1975). Moreover, the state's coastline had become much more heavily developed in the interim (McElyea et al., 1982). This raised the prospect of potentially larger disasters to come and provoked serious questions about the feasibility of existing coastal evacuation plans (Stone, 1983). Finally, there was a growing realization that the barrier islands that line North Carolina's oceanfront are particularly hazardous places. This concern produced a number of widely influential publications and fueled support for the state's innovative coastal hazard management program (Dolan, 1972; Moul, 1983; Owens, 1983; Pilkey et al., 1975; Pilkey et al., 1978; Soucie, 1976).

Emergency preparedness at the state level is the responsibility of the Division of Emergency Management within the North Carolina Department of Crime Control and Public Safety. The division maintains a headquarters Emergency Operations Center in Raleigh and also employs six area coordinators who act as contacts between the division and local emergency management coordinators in counties and municipalities. The state area coordinator for southeastern North Carolina oversees a 20-county region that includes five coastal counties (Carteret, Onslow, Pender, New Hanover, and Brunswick). The coordinator relays hazard warnings and supplies regionwide information on lead times necessary to complete evacuations in advance of hurricane landfall (Table 4.3).

TABLE 4.3 Evacuation Lead Times

County	Community	Hours Needed to Complete a Successful Evacuation Before Hurricane Landfall
Brunswick	Sunset Beach	13
	Ocean Isle Beach	13
	Holden Beach	17.5
	Oak Island[a]	14
	Southport	13.5
New Hanover	Pleasure Island[b]	12
	Wrightsville Beach	11

[a]Includes Long Beach, Yaupon Beach, and Caswell Beach.
[b]Includes Kure Beach, Wilmington Beach, and Carolina Beach.

Source: Vance Kee, North Carolina Division of Emergency Management, personal communication, 1984.

Other responsibilities are to coordinate postdisaster damage assessment and relief activities and to further state preparedness policies through conferences with public officials and training workshops for professionals. All county coordinators in coastal areas are paid government employees, although many are part-time personnel and hold more than one administrative position. Inasmuch as their effectiveness is enhanced by good rapport with local agencies and elected officials, there is an advantage to such dual roles. Nonetheless, there is considerable variation in the priority attached to emergency management among government functions.

The Division of Emergency Management has developed the North Carolina Disaster Relief and Assistance Plan. This outlines procedures to be followed by state and local governments in the event of a threatened or actual disaster (North Carolina Division of Civil Preparedness, 1976). The division has also prepared a prototype disaster relief and assistance plan for use by county governments (North Carolina Division of Emergency Management, 1981). Brunswick County relies largely on this general plan for hurricane disaster preparedness, although it includes a separate appendix entitled "Hurricane Safety Rules" (Brunswick County, n.d.). Individual Brunswick County communities also possess emergency management plans.

Pender County and New Hanover County possess more specialized hurricane evacuation and response plans (New Hanover County Civil Preparedness Agency, 1977; Pender County, 1984). On August 1, 1983, the

New Hanover County Board of Commissioners passed an ordinance requiring preparation of a hurricane protection study for the county's barrier islands. This is the first element in a two-year project to prepare a hurricane hazard evacuation, mitigation, and post disaster reconstruction plan. The study is funded by the North Carolina Office of Coastal Management. Several parts of this plan have been published (New Hanover County Planning Department, 1983, 1984). While the hurricane protection study was being completed, a 90-day moratorium on construction on barrier islands was in effect (New Hanover County Planning Department, 1983, p. 1). Various municipalities in New Hanover County also possess their own hurricane evacuation plans (e.g., Carolina Beach, Kure Beach, Figure Eight Island, Wrightsville Beach). An isolated, privately owned resort development on Bald Head Island, at the mouth of the Cape Fear River, has also instituted hurricane emergency procedures. These involve transportation of evacuees by boat to the mainland, and they rely entirely on the actions of corporate personnel. However, several parts of Bald Head Island are sufficiently elevated and protected to provide emergency refuges in the event that evacuation cannot be completed in safety.

Masonboro Island is the only large, unpopulated, and undeveloped island in the Cape Fear region. It lacks road access to the mainland and has a long history of overwash during hurricanes and accompanying inlet migration. Under the provisions of the 1982 Coastal Barrier Resources Act, Masonboro Island is considered to be undeveloped. No future development on it will be eligible to receive federal flood insurance coverage.

The U.S. Army Corps of Engineers in Wilmington is also conducting hurricane evacuation studies. A two-year eastern North Carolina hurricane evacuation study was begun in April 1984. A team of consultants is also making behavioral analyses of past, and likely future, human responses to warnings in support of this study. In addition, the National Hurricane Center is developing a computer simulation of storm surge inundation (the SLOSH model) for the Cape Fear region.

At present the National Weather Service attempts to provide hurricane warnings at least 12 hours before expected landfall, but it recognizes that, in practice, warnings may be issued with less lead time. The time required to evacuate several New Hanover County communities is pressing against the current capability of the warning system. For example, estimates of evacuation times for Wrightsville Beach vary from 10.61 hours (New Hanover County Planning Department, 1983), to 11 hours (Area Coordinator, North Carolina Division of Emergency Management), to 11.2 hours (New Hanover County Planning Department, 1984).

Hurricanes are not the only hazard that has stimulated local emergency preparedness in this area. The Brunswick Nuclear Power Station is located 5 miles upstream from the mouth of the Cape Fear River. Coastal communities from Carolina Beach to Long Beach (see Figure 1.2) lie within a 10-mile Emergency Planning Zone that surrounds the plant. Warning, evacuation, and sheltering plans (Figure 4.1) have been developed for this zone and are regularly tested. It is widely

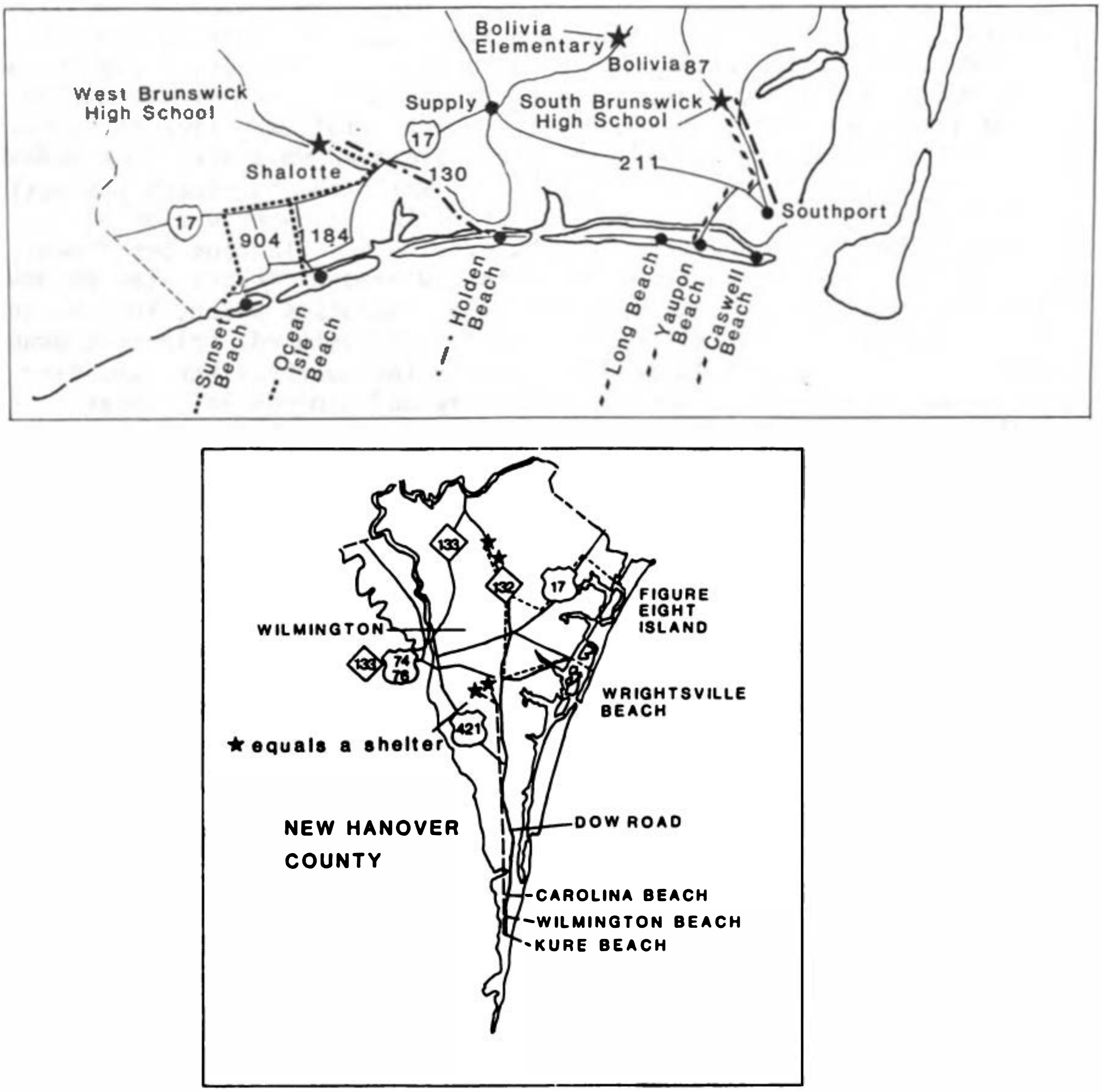


FIGURE 4.1 Evacuation routes for Brunswick and New Hanover counties.

believed that emergency planning for nuclear power station accidents does not reinforce levels of preparedness for natural disasters. Nonetheless, it is difficult to believe that residents of coastal areas are unaware of the conspicuously posted nuclear emergency evacuation routes that fan out through the entire Cape Fear region and terminate at shelters in greater Wilmington or other communities. On otherwise undisturbed rural roads that are the only evacuation hurricane routes for coastal residents in Brunswick County, these emergency evacuation signs are clearly visible.

IMMEDIATE RESPONSE TO DIANA

Warnings and Public Responses

Sources of Information

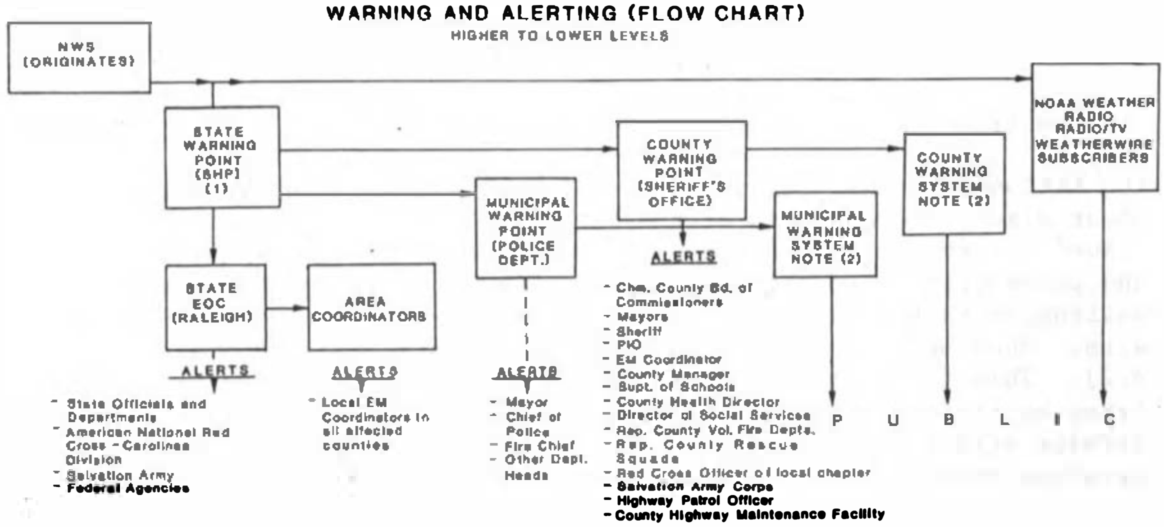
The National Weather Service provided two main sources of information about Diana. Forecasters at the National Hurricane Center in Miami issued advisories that emphasized the storm's position, track, speed, and probabilities of regional impact. These messages were broadcast nationally to the mass media over the NOAA Weather Radio and Weather Wire. They were also released over the National Warning System (Figure 4.2). This information led to most of the initial evacuation decisions taken by state and municipal emergency managers. The local Weather Service office in Wilmington also supplied information to residents via messages broadcast on radio and television throughout southeastern North Carolina and beyond. This information continued to reach the public throughout the passage of Hurricane Diana. Even at the storm's height, at least one radio station was still operating in the Cape Fear region.

Until the afternoon of Tuesday, September 11, more detailed information was provided from the National Hurricane Center. Thereafter, messages emanating from the Wilmington Weather Service Office contained more information, especially about specific locations at risk and about the timing and nature of recommended public responses. One of the Weather Service personnel at Wilmington was a sociologist sent by Weather Service headquarters with expertise in the field of human responses to hazard warnings. His role was to ensure that public warning and advisory messages about Diana contained readily understood information designed to encourage appropriate protective behavior by people at risk.

Prewarning Phase

An Air Force reconnaissance aircraft first located tropical storm Diana 150 miles east of Cape Canaveral at 2:45 p.m. EDT on Saturday, September 8. Three hours later the National Weather Service began issuing storm probability statements designed to help public officials start planning protection in advance of a formal hurricane warning (Carter, 1983). At that time the 24-hour probability of Diana passing within 65 miles of a coastal reference point was greatest for Daytona Beach, Florida (45 percent) (Table 4.4). There was a 14 percent probability that Wilmington, North Carolina, would be hit during the period between 6 p.m., September 8, and 6 p.m. September 11.

At 3:30 p.m. the following day (Sunday, September 9), Brunswick County Civil Defense officials received a hurricane alert message and immediately activated their Emergency Operations Center. (This took place some 50 hours before Diana first brushed the North Carolina coast on September 11, and 80 hours before the storm finally moved over land early on September 13.) Shortly thereafter (4 p.m., September 9), a hurricane watch was begun for the coast between St. Augustine, Florida,



NOTES:

(1) Warnings relayed by PIN. (Where no terminal, passed by phone/radio from nearest terminal by agreement.)
(2) County and municipal warning systems disseminate warnings to the public by use of radio/tv bulletins, loud speakers or other audible systems, and door to door, if necessary. (Law enforcement, rescue squads and volunteer citizens organizations are used to spread warnings when activated by the County Warning Point.)
(3) Warning alerts are also received via National Warning System.

FIGURE 4.2 The warning system.

and Oregon Inlet, North Carolina. The 72-hour probability of Diana hitting Wilmington had, by then, risen to 18 percent (Table 4.5).

Monday, September 10 At 8:15 a.m. a NOAA aircraft reported that Diana had become a hurricane with 80-mph sustained winds. Hurricane warnings were subsequently issued at 9 a.m. for coastal communities between Brunswick, Georgia, and Oregon Inlet. Wilmington's 72-hour probability was now 23 percent, with Charleston, South Carolina, recording the highest impact probability (35 percent within 17 hours) (Table 4.6).

Throughout the morning a wide range of hurricane preparedness activities were undertaken in the greater Wilmington area and elsewhere. These involved state and local governments, the American Red Cross, public utilities, mass media, hospitals, and private property owners. For example, the North Carolina Division of Emergency Management began reassigning area coordinators from inland sectors to coastal areas in anticipation of future disaster needs. The Brunswick County Hurricane Response Committee met to review preparedness plans and activities. The recently appointed Emergency Management Coordinator for New Hanover County convened a meeting at 11 a.m. of local disaster officials to discuss the need for activating Wilmington's hurricane plan. Tourists were asked to leave coastal resorts; the public was informed about siren and loud hailer procedures for disseminating evacuation warnings; maps of evacuation routes were published in local newspapers; and citizens were recommended to consult similar maps

TABLE 4.4 Probabilities Attached to the 6 p.m. Saturday, September 8, NHC Advisory

Coastal Locations	Additional Probabilities (percentage) Through 6 p.m. Sun.	6 p.m. Sun. Through 6 p.m. Mon.	6 a.m. Mon. Through 6 p.m. Mon.	6 p.m. Mon. Through 6 p.m. Tue.	Total Through 6 p.m. Tue.
ATLANTIC					
Florida					
Marathon	x	1	x	1	2
Miami	1	1	1	1	4
W. Palm Beach	6	1	1	1	9
Ft. Pierce	22	x	x	x	22
Cocoa Beach	37	x	x	x	37
Daytona Beach	45	x	x	x	45
Jacksonville	33	1	x	x	34
Georgia					
Savannah	15	3	1	1	20
S. Carolina					
Charleston	5	7	4	1	17
Myrtle Beach	1	7	4	3	15
N. Carolina					
Wilmington	x	5	5	4	14
Morehead City	x	3	5	4	12
Cape Hatteras	x	1	3	5	11
Virginia					
Norfolk	x	1	3	5	9
Maryland					
Ocean City	x	x	1	6	7
New Jersey					
Atlantic City	x	x	1	5	6
New York					
New York City	x	x	x	4	4
Montauk Point	x	x	x	4	4
Rhode Island					
Providence	x	x	x	3	3
Massachusetts					
Nantucket	x	x	x	3	3
Hyannis	x	x	x	3	3
Boston	x	x	x	2	2
GULF					
Florida					
Key West	x	x	1	1	2
Marco Island	1	2	1	2	6
Fort Myers	3	3	1	1	8
Venice	5	3	2	1	11
Tampa	14	2	x	1	17

TABLE 4.4 Continued

Coastal Locations	Additional Probabilities (percentage) Through 6 p.m. Sun.	6 p.m. Sun. Through 6 p.m. Mon.	6 a.m. Mon. Through 6 p.m. Mon.	6 p.m. Mon. Through 6 p.m. Tue.	Total Through 6 p.m. Tue.
Cedar Key	19	1	1	x	21
St. Marks	9	4	2	1	16
Apalachicola	3	6	1	2	12
Panama City	2	4	2	2	10
Pensacola	x	2	2	2	6
Alabama					
Mobile	x	1	1	2	4
Mississippi					
Gulfport	x	x	1	2	3
Louisiana					
Buras	x	x	1	2	3
New Orleans	x	x	1	1	2

Note: x means less than one percent.

printed in local telephone directories (e.g., for Pleasure Island). However, like Brunswick County and adjacent Pender County, New Hanover County authorities did not order an evacuation of coastal areas until the following day (Tuesday, September 11).

Local hospitals, the Carolina Power and Light Company, Southern Bell, the Brunswick Electric Membership Corporation, and the New Hanover County Airport (Wilmington Airport) all activated required emergency procedures. One of the two reactors at Carolina Power and Light's Brunswick Nuclear Power Station was already in a scheduled shutdown. The second reactor was shut down on Monday when lightning interfered with instrument control circuits. Neither reactor operated during Hurricane Diana.

Local beachfront municipalities at risk issued community identification stickers to residents so that only returning evacuees could be admitted to damaged areas after the storm passed. The American Red Cross prepared shelters at four locations in New Hanover County, and Brunswick County authorities laid plans to open several high schools as the need arose. Elsewhere, on Topsail Island, sand was bulldozed around exposed homes on the beachfront in an effort to provide protective berms. During the evening a bridge linking Sunset Beach with the mainland was closed for two hours at high tide (9 p.m. to 11 p.m.). At that time an estimated 100 people remained on the island. A limited number of voluntary evacuees from the north end of Carolina Beach began arriving in Wilmington shelters, and Brunswick County's West Brunswick High School was opened as a shelter.

TABLE 4.5 Probabilities Attached to the 4 p.m. Sunday, September 9, NHC Advisory

Coastal Locations	Additional Probabilities (percentage) Through 12 p.m. Mon.	12 p.m. Mon. Through 12 a.m. Tue.	12 a.m. Tue. Through 12 p.m. Tue.	12 p.m. Tue. Through 12 p.m. Wed.	Total Through 12 p.m. Wed.
Florida					
Jacksonville	36	x	x	x	36
Georgia					
Savannah	28	1	x	x	29
S. Carolina					
Charleston	22	2	x	1	25
Myrtle Beach	10	7	2	1	20
N. Carolina					
Wilmington	4	9	3	2	18
Morehead City	2	8	4	2	16
Cape Hatteras	1	5	5	3	14
Virginia					
Norfolk	x	3	5	4	12
Maryland					
Ocean City	x	1	3	5	9
New Jersey					
Atlantic City	x	x	2	5	7
New York					
New York City	x	x	1	5	6
Montauk Point	x	x	1	4	5
Rhode Island					
Providence	x	x	x	4	4
Massachusetts					
Nantucket	x	x	1	4	5
Hyannis	x	x	x	4	4
Boston	x	x	x	4	4
Maine					
Portland	x	x	x	2	2
Bar Harbor	x	x	x	2	2

Note: x means less than one percent.

TABLE 4.6 Probabilities Attached to the 9 a.m. Monday, September 10, NHC Advisory

Coastal Locations	Additional Probabilities (percentage) Through 2 a.m. Tue.	2 a.m. Tue. Through 2 p.m. Tue.	2 p.m. Tue. Through 2 a.m. Wed.	2 a.m. Wed. Through 2 a.m. Thu.	Total Through 2 a.m. Thu.
Florida					
Daytona Beach	19	x	x	x	19
Jacksonville	27	x	x	x	27
Georgia					
Savannah	30	1	x	x	31
S. Carolina					
Charleston	35	x	1	x	36
Myrtle Beach	27	1	x	1	29
N. Carolina					
Wilmington	18	3	1	1	23
Morehead City	9	8	1	1	19
Cape Hatteras	3	9	3	2	17
Virginia					
Norfolk	1	7	4	3	15
Maryland					
Ocean City	x	3	5	4	12
New Jersey					
Atlantic City	x	1	4	5	10
New York					
New York City	x	x	3	5	8
Montauk Point	x	x	2	5	7
Rhode Island					
Providence	x	x	1	5	6
Massachusetts					
Nantucket	x	x	1	5	6
Hyannis	x	x	1	5	6
Boston	x	x	1	4	5
Maine					
Portland	x	x	x	3	3
Bar Harbor	x	x	x	3	3
Eastport	x	x	x	2	2

Note: x means less than one percent.

Tuesday, September 11 On Tuesday, National Weather Service forecasters voiced uncertainty about Diana's future course. Mounting evidence then suggested that the storm would probably come ashore near nightfall in the area between Myrtle Beach, South Carolina, and Wilmington, North Carolina. Emergency management organizations initiated and completed major evacuations of coastal populations. Several potential problems arose during the day, but none significantly hindered evacuation.

Early on Tuesday morning (5:30 a.m.) an intragovernmental tropical cyclone discussion message from the National Hurricane Center noted divergent forecasts for Diana. The National Meteorlogical Center believed that the storm was likely to stall near its current position, whereas the National Hurricane Center forecast a north-northeast track at 6 knots. (This information was not released to the public. However, there is no apparent connection between these forecasting discrepancies, which occurred early on September 11, and the fact that some evacuees who left beachfront areas during the afternoon of September 11 returned prematurely on September 12.) By 6 a.m. Hurricane Diana advisory 14, from Miami, reported that the storm would move over the Carolinas within 12 to 24 hours and exhorted residents to be prepared to complete protective actions on short notice. The last hurricane probability statement was released at this time. It indicated that the most likely landfall lay in the vicinity of Myrtle Beach (37 percent) and Wilmington (34 percent) (Table 4.7). Three hours later a tornado watch for much of coastal North and South Carolina was issued by the National Weather Service's Wilmington office. No tornadoes were subsequently confirmed in nearshore districts.

Weather Service officials were eager to announce evacuation of coastal North Carolina as soon as possible after 6 a.m. They urged local and state leaders to start the evacuation process and began issuing advisory messages designed to prepare the public for imminent evacuation. At the request of North Carolina state officials, a formal National Weather Service recommendation for evacuation was delayed until Governor James Hunt had issued his own recommendation and declared a state of emergency. This occurred at 9:50 a.m., and evacuation areas were identified in Brunswick, New Hanover, and Pender counties. Similar recommendations were issued in South Carolina for Horry County and portions of Georgetown County. By this time, Diana had become a category 3 hurricane on the Saffir-Simpson scale with a central pressure of 959 mb and maximum winds of 120 mph. Rainfall in excess of 10 in. was forecast for coastal areas of the Carolinas, and a 12-ft storm surge was anticipated.

In Brunswick County, emergency preparations accelerated during the period between 10:30 a.m. and noon. The county control group was convened by the chairman of the board of county commissioners. This group normally includes mayors of 14 municipalities, but only one attended, although five others sent representatives. At 11 a.m. the county Civil Defense director issued an evacuation order for islands and low-lying areas. The target population was later expanded to include people living within 1 mile of the Intracoastal Waterway. Affected residents were directed to seven shelters located mainly in public schools. Local leaders in at least one shore community (Ocean Isle

TABLE 4.7 Probabilities Attached to the 6 a.m. Tuesday, September 11, NHC Advisory

	Additional Probabilities (percentage)				
Coastal Locations	Through 2 a.m. Wed.	2 a.m. Wed. Through 2 p.m. Wed.	2 p.m. Wed. Through 2 a.m. Thu.	2 a.m. Thu. Through 2 a.m. Fri.	Total Through 2 a.m. Fri.
Georgia					
Savannah	4	3	3	2	12
S. Carolina					
Charleston	23	1	x	x	24
Myrtle Beach	37	1	x	x	38
N. Carolina					
Wilmington	34	1	x	x	35
Morehead City	26	x	1	x	27
Cape Hatteras	14	4	1	1	20
Virginia					
Norfolk	4	7	2	3	16
Maryland					
Ocean City	1	4	3	4	12
New Jersey					
Atlantic City	x	2	3	4	9
New York					
New York City	x	1	2	4	7
Montauk Point	x	x	2	4	6
Rhode Island					
Providence	x	x	1	4	5
Massachusetts					
Nantucket	x	x	1	5	6
Hyannis	x	x	1	4	5
Boston	x	x	1	3	4
Maine					
Portland	x	x	x	3	3
Bar Harbor	x	x	x	2	2
Eastport	x	x	x	2	2

Note: x means less than one percent.

Beach) challenged the legitimacy of the "order" and waited until mid-afternoon before officially complying. According to surveys conducted by the Hazards Management Group (1985) after Diana, more than 20 percent of the beach area evacuees in the entire Cape Fear region had left by 11 a.m., and in the next 7 hours an additional 65 to 70 percent left. Most of the other evacuees (10 to 12 percent) did not leave until after Diana ended her stall. Many coastal communities were successfully evacuated by shortly after noon, and all within six hours. It is estimated that no more than 10 percent of potential island evacuees failed to leave, together with approximately 60 to 80 percent of those living in flood-prone inland areas. For example, approximately 2,500 people left Long Beach and only 39 remained.

State studies had recommended that evacuation of exposed areas in New Hanover County should begin not later than 11 to 12 hours before anticipated hurricane landfall (Table 4.3). It was expected that 8 to 10 hours would be needed to remove all potential victims at peak population periods and allow time for closure of roads due to winds and water rising ahead of the storm. At 10 a.m. Diana was forecast to reach the coast by evening. Yet official evacuation decisions were delayed until noon and later because emergency managers recognized that relatively few people were at risk in mid-September and evacuations could be accomplished quickly. Wilmington did not declare a state of emergency until 1 p.m., but local officials in oceanfront districts of New Hanover County (i.e., Carolina Beach, Kure Beach, and Wilmington Beach) began recommending evacuation around noon. At the urging of police equipped with loud hailers, most residents were gone by 3 p.m. About 20 families decided to remain in Kure Beach. Wrightsville Beach officials were able to seal off the mainland causeway by 4 p.m. Special shelter arrangements were made for the residents of retirement homes and patients in nursing homes. As the evacuations progressed, New Hanover County Airport ceased operations; ships moored in the Cape Fear River were moved upstream to safer berths; and 200 National Guards were mobilized for duty in Wilmington.

Minor problems were reported elsewhere in North Carolina. In Pender County, 200 evacuees were moved 12 miles inland from primary shelter in Topsail Junior-Senior High School after Weather Service forecasters projected that Diana could come ashore near Topsail Island. In Onslow County, traffic jams occurred on N.C. Route 210 as rising water submerged access to a bridge linking northern Topsail Island with the mainland. Police redirected island residents south to an alternative crossing without losses, and the island was successfully evacuated. A total of 3,000 residents were sheltered in 6 schools and 12 churches throughout Onslow County during the night.

Damaging winds and accompanying electrical outages began to affect the Cape Fear region in late afternoon. Wind gusts increased from 55 mph (Oak Island Coast Guard Station, 4 p.m.), to 70 mph (Holden Beach and Sunset Beach, 6:50 p.m.), to 115 mph (Oak Island Coast Guard Station, 7:45 p.m.). As the hurricane's leading edge moved toward shore, the dominant coastal wind direction was from the north. Meanwhile, Diana's peak winds offshore exceeded 130 mph. Brunswick County officials ordered emergency personnel to seek shelter at 4:40

p.m. By 6 p.m. more than 3,600 people occupied shelters in Brunswick County, with 1,250 more in similar New Hanover County shelters. The Red Cross announced that 7,000 were being housed in 31 shelters throughout a six-county area (New Hanover, Brunswick, Columbus, Bladen, Pender, and Onslow counties). Many others are believed to have sheltered in approximately 60 churches scattered throughout Brunswick County and New Hanover County.

According to the Hazards Management Group surveys, only 10 percent of the beach area evacuees in the area went to public shelters. An estimated 65 percent went to friends' and relatives'; 15 percent went to motels; 10 percent went to churches, public buildings, workplaces, etc; and 70 percent went out of town (i.e., several miles inland). An estimated 20 to 25 percent of the mainland evacuees used public shelters, with only 40 percent going inland.

Apart from fallen trees, the first significant reported damage to property occurred at 6:30 p.m., when a condominium apartment building under construction in Carolina Beach suffered severe wind damage. Thereafter, damage was also sustained at piers in Kure Beach and Wrightsville Beach and at the Brunswick County Airport terminal building. By 10 p.m. Carolina Power and Light confirmed that 7,700 local customers were without electrical power.

Wednesday, September 12 Diana's expected landfall did not occur on Tuesday night. Wednesday was also anticlimatic as the storm moved slowly and erratically offshore while beginning to lose strength. Despite cautionary, but uncertain, statements from the National Weather Service and local officials, most of Tuesday's evacuees returned home during Wednesday, thus exposing themselves to renewed risks as Diana resumed moving toward land on Wednesday night. Many were successfully reevacuated to inland shelters, but significant numbers were forced to remain on several islands in Brunswick County.

Sustained wind speeds gradually decreased from a maximum of 90 mph at 4 a.m. (Fort Fisher), as Diana pulled back to sea. It became increasingly difficult to make definite forecasts of the hurricane's course. The National Hurricane Center reported in an intermediate advisory at 10 a.m. that "this morning we have a hurricane with no sense of direction" and at 1:00 p.m. urged users to "exercise caution in speculating on the future course of Diana based on short term trends indicated by the hourly positions." These uncertainties were reflected in statements issued by the local Weather Service office in Wilmington. Prior to 5 a.m. all local residents were advised to remain sheltered. At that time a new statement from Wilmington indicated that "no one should attempt to return to [barrier island] beaches until the winds subside later today" (advisory 27). By 11 a.m. this had been replaced by clear-cut advice to stay away from beach communities (advisory 30), with the emphasis "until further notice" added in later advisories (advisory 31).

In New Hanover County, evacuees began returning to Pleasure Island (which includes Carolina Beach, Wilmington Beach, and Kure Beach) by late morning. Further north, Wrightsville Beach and Topsail Island remained closed to returning evacuees throughout the day. Several thousand people also left Brunswick County shelters during the morning. They returned to Caswell Beach, Yaupon Beach, Long Beach, Holden Beach, and other communities when town governments rescinded, or did not continue, evacuation recommendations. For example, approximately 2,000 people came back to Long Beach at this time.

Emergency management officials in Brunswick County closed one shelter on Wednesday after the evacuees departed, but they did not rescind Tuesday's evacuation orders. Instead, at 7:30 p.m. they issued a renewed call for evacuation of all beach areas and added a fourth public school to the list of official mainland shelters. A majority of the returned evacuees were reevacuated at this time. However, a significant number of people could not be reevacuated before bridges to the mainland were closed due to rising winds. For example, 250 people were housed in two churches and a recreation center on Long Beach. None of these buildings were designed to function as secure shelters, but all survived intact. By contrast the joint police-fire department building in Long Beach suffered heavy loss and was subsequently declared unsafe.

The extent to which evacuees returned home on Wednesday is not fully known. Red Cross officials reported that 7,074 people were housed in 33 shelters on Tuesday night but that only about 3,500 remained in the 16 shelters still open at 9 a.m. on Wednesday. The Hazards Management Group surveys suggest that 40 percent of the evacuees returned home on Wednesday. Local emergency managers estimated that 80 to 90 percent of the residents in all oceanfront municipalities except Wrightsville Beach and Topsail Island returned home at some time on Wednesday.

Thursday, September 13 The eye of hurricane Diana finally made landfall near Fort Fisher between 2 a.m. and 3 a.m. Peak sustained winds of 85 mph, gusting to over 100 mph, were reported at Carolina Beach. The storm continued drifting west, parallel with the coast, until late morning. Most of the circulation remained over the ocean, with sustained winds fading from 90 mph (6 a.m.) to 75 mph (10 a.m.) and finally to 50 mph (6 p.m.). By this time Diana had turned north over Columbus County, 35 miles west of Wilmington. All warnings were discontinued at 6 p.m. Later in the evening Diana began recurving toward the north-northeast.

As Diana moved onshore, residents of the Cape Fear region remained in shelters throughout much of Thursday and throughout Thursday night. At 5 a.m. Red Cross personnel estimated that approximately 12,000 people had taken shelter at 49 facilities in 13 countries.

Power outages caused by Tuesday night's high winds had been ended for all but 1,000 customers when renewed high winds began on Thursday morning. By 2 a.m. most radio and television stations had ceased to operate. Only WAAV radio station in Wilmington managed to keep broadcasting using an emergency diesel generator. The station continued to issue hurricane reports throughout the night for residents with battery-powered radios. These bulletins were based on information phoned in by listeners, reports relayed from sister stations in

Fayetteville, North Carolina, and other sources. Power supplies were partially restored to the mass media at 8:05 a.m., but several stations remained off the air until Thursday night.

At 6 a.m. hurricane warnings were discontinued for the area north of Wilmington but remained in effect as far south as Myrtle Beach, South Carolina. High water forecasts were scaled down at 6 a.m. to 5 to 8 ft above normal and at 10 a.m. to 5 ft above normal. Ten to 15 in. of rain were expected.

By noon winds had dropped to 75 mph or less, and the occupants of shelters began phoning the National Weather Service to find out when they should return home. Already, farther north in Pender and Onslow counties, emergency shelters were being deactivated and residents were being readmitted to Topsail Island. By 3 p.m. roadblocks had been removed from N.C. Routes 210 and 50 at Surf City. About 6 p.m. all warnings were discontinued by the Weather Service. However, apart from residents of Wrightsville Beach who came back on Thursday, most oceanfront property owners in the Cape Fear region did not return home until the following day or thereafter.

Friday, September 14, and Succeeding Days Diana passed out to sea north of Cape Hatteras late on Friday. Subsequently, the storm reintensified over the ocean, attaining maximum wind speeds of 65 mph, and accelerated northeast at 45 mph. The remnants of Diana finally began to lose intensity on Sunday, September 16, as they passed over southeastern Newfoundland.

By daybreak, normal weather conditions prevailed over most of the Cape Fear region. People returned earlier to beachfront communities in New Hanover County than in Brunswick County. At 7:30 a.m. residents of Carolina Beach, Wilmington Beach, and Kure Beach were given access to the southern oceanfront districts--the last areas of New Hanover County to be reopened to the public. Later in the day, residents of Holden Beach, Ocean Isle Beach, and Sunset Beach in Brunswick County began returning home. Reports from Bald Head Island indicated that residents there had survived Diana without injury.

Progress was slower on Oak Island, partly because of a report that PCBs had leaked from damaged transformers. Althought the first residents began to return to Yaupon Beach on Friday, downed power lines blocked access to Long Beach for most of them until Saturday. Beachfront areas were not reopened until early on Sunday, September 1.

Warnings and Evacuation: An Overview

The warning and evacuation process for Hurricane Diana was complicated by the storm's erratic behavior. National Weather Service personnel in Wilmington reported that there were seven distinct phases of threat during a 60-hour period: (1) storm offshore but no definite indication of landfall in the Cape Fear area; (2) storm begins moving toward Cape

Fear; (3) landfall by a category 3 hurricane expected; (4) diminished, uncertain, but potentially serious threat as Diana loops offshore; (5) second landfall expected (category 1 hurricane); (6) storm weakens slowly as it moves over land; and (7) possibility of inland flash floods in the wake of Diana (T. Michael Carter, National Weather Service, personal communication).

Each of these phases necessitated changes in public advisory messages, including statements about evacuation and other protective actions. Thus, on Monday, September 10, local residents were initially alerted to the need for vigilance and preparedness. On Tuesday, September 11, they were advised to evacuate oceanfront areas and subsequently told to remain inside secure buildings. During Wednesday's hiatus the initial emphasis on remaining in shelters gave way to cautions about not venturing back to shorefront communities until winds subsided. Later the public was encouraged to stay away from beach communities altogether. Eventually, when Diana again turned toward land, people were recautioned to seek safe shelters. On Thursday, September 13, residents were advised to remain indoors, and those occupying low-lying sites were requested to prepare for moves to higher ground if flooding occurred.

Hurricane probability information was of some limited help in encouraging state and local emergency managers to prepare for warning and evacuating people at risk. But it does not appear to have stimulated a significant number of decisions by individuals to evacuate. A hurricane warning was in effect for most of the North Carolina coast from 9 a.m. on Monday, September 10, but few local evacuations were begun until around noon on Tuesday, September 11--approximately six hours after the last probability statement was released.

Diana's complex behavior significantly increased the uncertainty attached to Weather Service forecasts. This clearly shows in the frustrated tone of some statements released to the public and--even more so--in messages intended for limited intragovernmental distribution. In one such message (the tropical cyclone discussion from Miami for 5:30 a.m., Tuesday, September 11), differing interpretations by Weather Service personnel in Washington, D.C., and Miami are clearly evident.

Diana had the potential to sow confusion throughout the warning and evacuation system as well as among the affected populations. Yet no confusion arose. At one point there was limited disagreement between the forecasts of the National Hurricane Center and those of the National Meteorological Center. This information was not publicly released and it had no apparent effect on the responses to warnings. The frequently changing protective information included in advisories was both clear and appropriately matched to the state of forecasting knowledge. Afterward, no one reported that they had failed to understand Weather Service advisories, through some complained about their tentativeness. The fact that substantial numbers of people returned to beachfront communities while Diana still threatened was due to disregard of Weather Service warnings, not to misinterpretation.

THE AFTERMATH OF DIANA

Diana's aftermath was marked by rapid recovery accompanied by debate about the effectiveness of existing hurricane mitigation measures and the need for additional mitigation initiatives. For most residents the storm's physical effects were of short duration. Within a day of the storm's departure, shelters emptied, businesses opened, the mass media were being restored, and government offices resumed operations (September 13-14). By Monday, September 17, schools reopened and virtually all customers were receiving full electrical power.

Most minor repairs to buildings were nearing completion within a week of the storm. During the study team's visit, scattered buildings that received significant damage remained largely untouched, but no major community reconstruction programs were contemplated or needed. For some community leaders the lack of widespread damage suggested that coastal areas could safely accommodate additional development. Other observers argued that there was insufficient evidence to support that judgment.

Costs of Damage

Estimated total damages of $78.9 million resulted from Hurricane Diana. Based on postdisaster estimates by state agencies, housing bore the brunt of private property losses ($30.1 million). However, it is difficult to be certain of the precise magnitude and distribution of housing losses because of differences in reporting and classification systems. For example, Red Cross tabulations of housing damage are based on reports volunteered by people seeking assistance and on field surveys subsequently undertaken by Red Cross personnel. Typically, large numbers of properties with very minor damage are included, perhaps creating an exaggerated impression of total losses. Conversely, victims are in a better position to report interior losses that may not be discernible to outside observers conducting windshield surveys.

According to Red Cross data, approximately 5,700 dwelling units suffered damage in North Carolina. Most of these were located in oceanfront communities of New Hanover County and Brunswick County (Table 4.8). The worst affected areas included Carolina Beach, Wilmington Beach, and Oak Island. Nearly 400 dwelling units sustained significant damage in these places. A large proportion of total housing damages were attributable to saturation of building contents by heavy rainfall following loss of roofs, shingles, porch screens, or glazing to high winds. Two previously threatened beach homes on Topsail Island were heavily damaged by erosion and waves.

A more detailed assessment of building damage was conducted by Spencer Rogers, a professional engineer employed in the U.S. Sea Grant Program's Marine Advisory Service in Kure Beach (Rogers, 1985). Based on personal inspection of all buildings located within three blocks of the ocean that had suffered discernible external damage, he concluded that 136 buildings had received significant structural damage. This represents 2 to 4 percent of the existing buildings in the surveyed

TABLE 4.8 Losses to Housing

Location	Number of Dwelling Units Destroyed	Major Damage	Minor Damage	Total
New Hanover County				
Wrightsville Beach	3	13	1,255	1,271
Carolina Beach	4	186	488	678
Wilmington Beach	22	60	297	379
Kure Beach	0	20	298	318
Other areas (e.g., Wilmington)	2	34	549	585
Brunswick County				
Oak Island[a]	11	114	964	1,089
Holden Beach	1	35	594	630
Ocean Isle Beach	0	2	135	137
Sunset Beach	0	0	15	15
Other areas	5	55	337	397
Other N.C. counties	4	3	193	200
Total	52[b]	522[c]	5,125[d]	5,699

[a]Includes Long Beach, Yaupon Beach, and Caswell Beach.
[b]15 single-family homes, 20 mobile homes, and 17 apartments.
[c]405 single-family homes, 60 mobile homes, and 57 apartments.
[d]3,824 single-family homes, 380 mobile homes, and 917 apartments.

Note: 72 dwelling units were reported damaged in Horry County, South Carolina.

Source: American Red Cross, personal communication, 1984.

areas of coastal communities. Inasmuch as damage to shingles, doors, windows, and interiors was not included, this assessment omits many properties that would have been included in the Red Cross tabulation.

Federal flood insurance claims were submitted for 376 homes and small businesses. Of these, 127 were judged eligible for reimbursement. Total flood insurance payments exceeded half a million dollars ($518,328.36) with average payments amounting to $4,081. The majority of reimbursements affected properties in New Hanover County (99). Property owners in Carolina Beach and adjacent communities received the bulk of these funds.

Business losses were relatively minor ($5.1 million). By the end of October 1984, 34 business claims for Small Business Administration assistance had been received (FEMA, personal communication). A handful of motels, garages, and other small businesses suffered significant structural damage, but most business losses involved destruction of signs, outdoor lighting, and window glass. Two hundred and sixty-three people applied for unemployment assistance in the wake of Diana, but average reimbursements were small (approximately $60).

Hurricane Diana came at the end of a year that included a prolonged (73-day) drought. Significant agricultural losses ($26.5 million) were anticipated over a wide area of southeastern North Carolina. Estimated losses of $5.3 million were expected in Brunswick County alone. Damage was due to a combination of high winds and heavy rain at a time when food crops awaited harvest. Loss of electrical power to tobacco drying sheds may have caused extensive spoilage. Pecan trees and farm buildings also suffered damage.

Estimated costs of damage to public property were $17.2 million. Representative losses included destruction of the municipal water tower at Carolina Beach; wind damage to municipal buildings (e.g., at Long Beach); disruption of infrastructure (e.g., a suspected break in the water line between Long Beach and Holden Beach); and widespread clogging of drains, sewers, bridges, and culverts by sediment and debris. Debris removal costs accounted for 60 percent of federal assistance to local governments (i.e., $790,000). Pender County and several towns elsewhere (e.g., Ocean Isle Beach, Wrightsville Beach) reported losses of beach sand, but this was not generally included in damage totals.

Disaster Declaration

Diana arrived in the middle of a U.S. Senate election campaign between the incumbent, Jesse Helms, and the governor of North Carolina, James Hunt. Both candidates demanded, early and forcefully, that the area should receive a Presidential disaster declaration. Preliminary estimates by the FEMA damage survey team suggested that losses were relatively light, and officials from FEMA's regional office did not recommend such a declaration. Some local officials expressed strong disagreement with the survey data and alleged that assessors made "high-handed" judgments. Supplementary data were secured, and a Presidential disaster declaration was issued on September 21, one week after Diana finally came ashore. The declaration directed assistance for both public and private losses to three counties (Brunswick, New Hanover, and Pender) and assistance for public losses alone to three additional counties (Bladen, Columbus, and Sampson).

Debris Clearance and Restoration of Communications

Twenty-four hours after Hurricane Diana passed inland, most major roads and local streets had been reopened to traffic. Downed power lines and blocked roads prevented the return of residents to beachfront areas until late on Thursday, September 13 (Wrightsville Beach), or early on Friday, September 14 (e.g., Carolina Beach, Ocean Isle Beach, Holden Beach, Sunset Beach). Most oceanfront communities possess few large trees, but downed trunks and broken branches made up the bulk of surface debris in inland locations like Wilmington. Municipal sanitation personnel and private tree removal firms were overburdened by the clearance task, and officials in Wilmington sought assistance from neighboring military bases. One week after the storm, several city streets were still littered with debris.

Most businesses and public facilities had reopened by Friday, September 14, but schools remained closed for two days (September 13-14) in a four-county area (New Hanover, Brunswick, Pender, and Columbus). Brunswick County schools were also closed on Monday, September 17.

Roads and streets were covered by localized flooding at a few locations. In Carolina Beach, heavy rain and poor drainage caused Carolina Lake to overflow into adjoining streets. These remained closed for two days. On Friday, September 14, the Cape Fear River flooded N.C. Route 53 east of Burgaw in Pender County. This may have been a delayed response to Diana's heavy rainfall. The road was impassable during the following weekend, and 27 nearby families, constituting 45 people, were evacuated to emergency shelters.

Most radio and television stations resumed broadcasting at full power the day after Diana, and few subscribers were without electrical power for more than two days. Table 4.9 illustrates the rapid pace at which electricity service was restored in the Cape Fear region. Few people lost telephone service because 75 percent of Southern Bell's lines are laid underground. Approximately 1,500 of the company's 75,000 subscribers were adversely affected. Although delays in placing calls were common for several days, only in Carolina Beach and Long Beach were subscribers without service by Monday, September 17. Total restoration of telephone service was accomplished soon thereafter.

Emergency Services: Food, Shelter, and Medical Treatment

Red Cross Mass Care officials estimated that approximately 25 percent of evacuees were housed in public shelters before, during, and immediately after the storm. A disproportionately large number of those in public shelters probably came from inland communities. According to the Hazards Management Group surveys, only 10 percent of the beachfront evacuees reported entering public shelters. Many others rented space in hotels or stayed in private homes, and a significiant proportion of the seasonal occupants returned inland to their primary residences. More than 60,000 (63,772) people were housed and fed in 120 Red Cross shelters throughout North and South Carolina during the course of Hurricane Diana. Maximum attendance occurred on the night of September 12, when 32,000 to 36,000 people crowded the facilities. Because more evacuees were vacationers in South Carolina, shelters in that state contained more people that did shelters in North Carolina. For example, 26 shelters in Horry County housed a total of 32,607 individuals over a two-day period, whereas 7,017 attended 8 shelters in Brunswick County

TABLE 4.9 Resumption of Electricity Supplies

Date	Estimated Numbers of Customers Without Power	
	Carolina Power and Light Company	Brunswick Electric Membership Corporation
Sept. 11, 1984	16,000	No data
Sept. 12, 1984	1,000	No data
Sept. 13, 1984	45,000	20,000
Sept. 14, 1984	20,000	No data
Sept. 15, 1984	2,000	6,000-8,000
Sept. 16, 1984	100	3,000
Sept. 17, 1984	0[a]	0[a]

[a]Anticipated.

and 3,419 entered 4 shelters in New Hanover County. Most shelters were occupied for only two nights, September 11 and 12, but the last emergency shelter, in Pender County, did not close until the night of September 17.

Emergency feeding was provided by the Red Cross and the Salvation Army. Seventy-six Salvation Army personnel staffed mobile canteens and other feeding stations. They served nearly 10,000 meals to victims and relief workers in a four-day period after the storm (i.e., until Sunday, September 16).

There were few demands for medical treatment. Hospitals and Red Cross nurses reported no significant volume of storm-related casualties.

Disaster Assistance

Three Red Cross assistance centers were opened on Monday, September 17, in Wilmington, Carolina Beach, and Southport. Based on their experience with other disasters, Red Cross personnel estimate that, normally, 60 percent of people who report suffering damages subsequently ask for Red Cross assistance. However, in the case of Hurricane Diana, only 10 percent were expected to seek aid (about 600 people). By Thursday, September 20, approximately 450 families had registered for assistance, mainly in the form of food and clothing. Slightly more of these came from the Carolina Beach area than from elsewhere.

The study team completed its field investigation before a Presidential disaster declaration was issued on September 21. It is known that FEMA established disaster assistance centers to provide extended reconstruction and recovery aid as a consequence of the declaration. One thousand forty-four people registered for aid in the following six weeks (i.e., by October 29). By late October, 747 claims for individual family grants had been filed. The average size of reimbursements was smaller ($1,185) than anticipated ($1,667). Three hundred ninety-nine families and individuals had been provided with temporary housing, and no additional demands were expected. The Small Business Administration also received 107 applications for housing assistance. Total federal government obligations for postdisaster assistance to individuals were estimated at just under $10 million ($9,740,000), with the largest projected outlays being made by the Small Business Administration ($5 million) and the Federal Insurance Administration ($2.5 million). Direct federal assistance to local governments was estimated to exceed $1.2 million, mostly for debris removal ($790,000). Private nonprofit facilities were likely to receive an additional $600,000 in federal assistance. Estimated total federal outlays for disaster assistance equaled $11,575,000.

Hindsight Analysis

The performance of emergency management organizations during major disasters is sometimes subject to hindsight analysis by the agencies themselves and other groups. Hurricane Diana has attracted little of this attention, largely because it inflicted only small-scale damage. For example, the Federal Emergency Management Agency did not send a hazard mitigation team, nor did researchers conducting a major National Science Foundation-funded study of posthurricane redevelopment devote much concern to Diana. Formal studies of the National Weather Service's role have not been undertaken. Local newspapers carried generally positive evaluations of the performance of public agencies, utilities, mass media, and political leaders, although some criticisms were leveled at reporters who had exaggerated damage and broadcasting stations that lacked adequate backup electric power sources.

Apart from the present study and in-house analyses by local emergency managers, newspaper editorials, and informal evaluations by single researchers, no significant hindsight analyses are known. One other analysis of individual public responses to Hurricane Diana is ongoing. This consists of a series of telephone interviews with 100 mainland and 100 beach residents of southern North Carolina (Hazards Management Group, Inc. 1985). It is one component of the behavioral analyses undertaken to support a North Carolina hurricane evacuation study funded jointly by the U.S. Army Corps of Engineers and FEMA.

Redevelopment

Redevelopment was not a major issue because heavily damaged properties were few and scattered. New Hanover County did not suspend building permit requirements in the wake of the storm but waived permit fees for a 30-day period. Since nonstructural repairs costing less than $5,000 are normally exempt from the requirement to obtain a building permit, this action had minimal impact on poststorm recovery.

Prospects for Improving Hazard Mitigation for Hurricanes

Although most effort is now devoted to postdisaster relief and predisaster preparedness measures, U.S. public policies recognize that reduction or elimination of disasters can best be accomplished by adoption of more effective hazard mitigation programs. Disasters highlight the need for mitigation and sometimes provide opportunities to begin or modify mitigation practices.

Existing Mitigation Measures

Hazard mitigation for hurricanes is actively pursued in coastal areas of North Carolina. This is in contrast to many other parts of the nation, where preparedness and emergency management are often the only public responses (National Research Council, 1983b). Here mitigation efforts rely on a combination of measures that include, among others, (1) a strong state building code, (2) underground burial of telephone lines, (3) special state management and development controls for hazardous coastlines, (4) the National Flood Insurance Program, and (5) the federal Coastal Barriers Resources Program (McElyea et al., 1982)

North Carolina State Building Code North Carolina has a standard statewide building code that takes precedence over local codes (see Chapter 3). It was first adopted in the wake of Hurricane Hazel in 1954 and began a policy that required elevation of all oceanfront homes at least 8 ft above ground level. It now also requires that all new buildings located east of the Intracoastal Waterway (i.e., in maritime districts) be constructed to a 120-mph design wind speed. For counties immediately west of the waterway, the design speed is 110 mph (Figure 4.3). A variety of special provisions cover the design and installation of pilings and foundations, the quality of materials, hazard protection structures like bulkheads and groins, and requirements for upgrading older buildings that are damaged beyond 50 percent of their value.

During 1977 the state began mandatory inspections of new construction in larger communities. By July 1985 inspection will be mandatory in all communities. Implementation of the code is in the hands of professionally trained building inspectors. At present, New Hanover County employs inspectors, whereas a building inspector is not due to be appointed in Brunswick County until July 1985. Individual coastal municipalities in both counties retain building inspectors.

A separate North Carolina Residential Building Code has been developed for one- and two-family dwellings (see Chapter 3). Appendix D of the code, entitled "Wind Resistive Construction," applies to coastal communities subject to winds of over 75 mph. Adoption of the appendix is a local option, not a mandatory provision. Although New Hanover County has not adopted these regulations, all beachfront communities have.

The State of North Carolina Regulations for Mobile Homes constitute a third element of the building code. These prescribe construction and tie-down requirements.

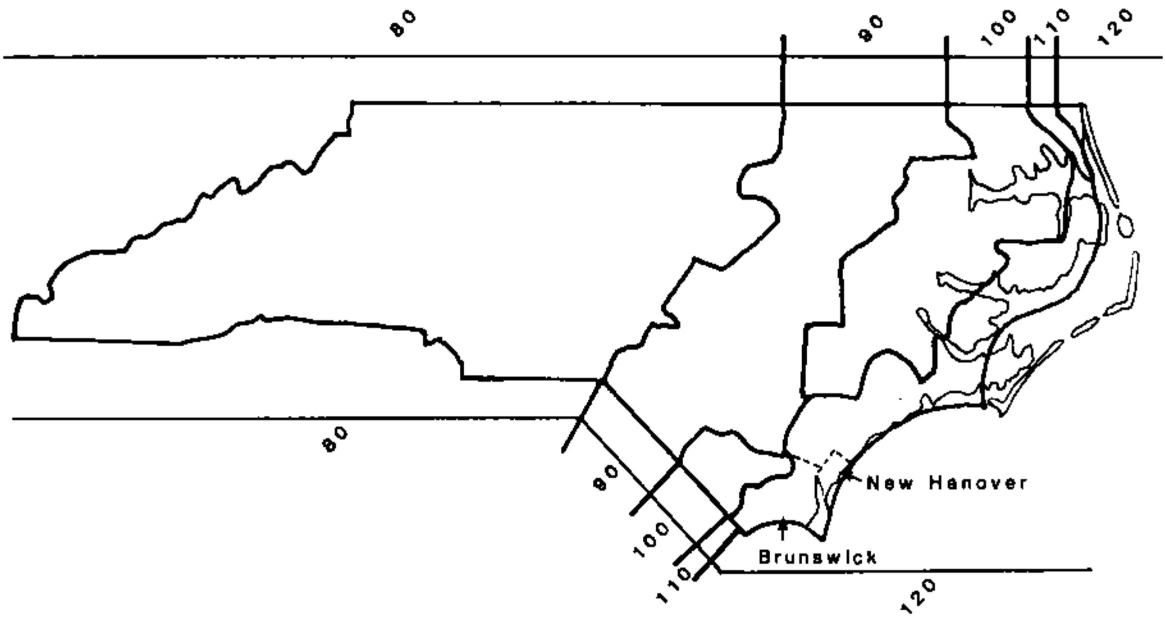


FIGURE 4.3 Critical design wind speeds in the North Carolina state building code.

In 1983 the North Carolina Building Code Council created a mitigation committee to study code revisions for coastal construction. This body was due to report its recommendations on September 11, when Diana first arrived on the coast. The most important recommended changes concern (1) elevating lowest floors above storm wave heights, (2) sinking pilings 5 ft below mean sea level in oceanfront erosion hazard zones, and (3) requiring that all corrosion-prone metal connectors be protected from oxidation.

Underground Burial of Telephone Lines Southern Bell has buried approximately 75 percent of its lines in the Cape Fear region. It is not known whether this is an explicit hazard mitigation measure, but the effect is to increase the survivability of communications during storms (Angel, 1984).

Coastal Hazard Management Regulations The state of North Carolina approved a wide-ranging Coastal Area Management Act (CAMA) in 1974. This requires that developers secure permits for "major" and "minor" works in "areas of environmental concern" (AECs) such as oceanfront zones and estuaries. Oceanfront hazard zones include exposed beaches, dunes, and inlets that are susceptible to erosion and flooding. Estuarine system AECs consist mainly of wetlands, estuarine shores, and associated waterways.

General Use Standards for Ocean Hazard Areas have been adopted. These are designed to ensure that existing dunes are maintained, that new buildings are set back behind primary dune or vegetation lines, and that publicly supported infrastructure systems are discouraged. All new structures must comply with Appendix D of the North Carolina Residential Building Code, and more stringent regulations affect highly dynamic inlet areas. Similar regulations affect development in estuarine system AECs, although the emphasis is on preservation of natural barriers to flooding and erosion and maintenance of estuarine productivity.

Other sections of CAMA contain additional mitigation provisions for hurricanes. The act sets limits to the amount of postdisaster repairs and redevelopment that can be undertaken without a CAMA permit, and it establishes a working relationship between the Coastal Resources Commission (CAMA's administrative authority) and the North Carolina Department of Crime Control and Public Safety (the lead agency for emergency management). Here the commission's responsibilities include streamlined postdisaster permit procedures and requirements that local governments include disaster planning in land use plans. The state is believed to have a posthurricane redevelopment plan, but there was little occasion for its use in the wake of Diana.

Local municipalities also possess a variety of ordinances and other measures aimed at enhancing hazard mitigation. These include resort room taxes to provide funds for beach nourishment and sand dune conservation regulations.

National Flood Insurance Program The general outlines of the National Flood Insurance Program (NFIP) are well known and do no need to be reported here. Many, if not most, coastal buildings at risk in the Cape Fear region comply with mitigation requirements for elevation of ground floors above base flood levels. Relative to the number of housing units in oceanfront communities of Brunswick County, flood insurance adoption rates vary from 13.5 percent at Yaupon Beach to 63.1 percent at Ocean Isle Beach. Information on the extent to which other mitigation provisions of the Flood Insurance Program have been adopted is unavailable.

Coastal Barrier Resources Act The Coastal Barrier Resources Act of 1982 prohibits federal assistance for development purposes on 186 undeveloped barrier beaches and islands along the Atlantic and Gulf coasts of the United States. Eight of these units, totaling 49.1 miles of shorefront, are located in North Carolina. They include Masonboro Island (9.1 miles) and part of Wrightsville Beach (1.1 mile), which are both in New Hanover County; the Lea Island complex (2.1 miles), which is shared between New Hanover County and Pender County; and parts of Topsail Island (6.3 miles) and Onslow Beach (9.7 miles) in Onslow County (U.S. Department of the Interior, 1983). Beginning on October 1, 1983, federal flood insurance coverage became unavailable for new developments in these places.

Studies by the New Hanover County Planning Department have evaluated development pressures and contraints on Masonboro Island (New Hanover County Planning Department, 1983). Recommendations of this study include prohibiting future residential use of such undeveloped barrier islands. Much of Masonboro Island suffered overwash during Hurricane Diana.

Mitigation in the Wake of Diana

The extent to which the foregoing mitigation measures will be augmented or weakened in the light of Hurricane Diana is difficult to assess. Without extensive damage to buildings and infrastructure, there was no stimulus for improving mitigation as part of a general reconstruction program. However, an emerging debate about the safety of coastal construction may have significant long-term consequences for the Cape Fear region. This was initiated by Wilmington's mayor William Schwartz, who noted that "The building codes apparently have been strengthened so you can build on the beach. . . . I think it will encourage people to come down here and build" (Schwartz, 1984). These comments represented the most optimistic end of a spectrum of contrasting views. Other local leaders took more neutral positions, pointing out, for example, that Diana might have reduced the willingness of banks to lend money for additional coastal construction, particularly in Carolina Beach. At least one engineer argued that, while coastal buildings generally stood up well to Diana's moderate winds and minimal storm surge, the present North Carolina building code needed strengthening to require deeper pilings for larger oceanfront buildings. Other observers cautioned that Diana was a relatively minor hurricane and should not lull coastal residents into a false sense of security.

However the debate is resolved, Diana's effect on hurricane mitigation activities seems likely to be minimal. Actions to strengthen mitigation that were already in progress before the storm will probably proceed, but no additional initiatives are forthcoming as a direct result of Diana.

SUMMARY

The Cape Fear region fared well during Hurricane Diana. Deaths, injuries, and property losses were minimal considering the numbers of people and scale of developments at risk in this diversified metropolitan area. For most residents, and the few visitors who were present, Diana's most significant effect was probably the disruption of normal activities over a four-day period prior to, during, and immediately after the storm made landfall. Many coastal homeowners spent two nights or more in public emergency shelters or other buildings while awaiting the outcome of Diana's uncertain behavior. Although the content of the National Weather Service's messages changed often, the information was generally timely, clear, and helpful, and residents were kept well informed about the storm's progress. Radio broadcasts did not cease, nor was telephone service seriously disrupted. Indeed, Diana clearly demonstrated the value of laying telephone and electricity lines underground in areas susceptible to hurricane-force winds.

Despite these generally positive results, there is no reason for complacency about public readiness to cope with hurricanes in North Carolina or elsewhere on the Atlantic coast. Several potentially serious flaws in preparedness, responses, and mitigation measures were revealed during Diana's passage. Some of these affected only one or two local communities. Others are general problems. In view of the fact that Diana was a weak hurricane when it finally came ashore, such flaws give reason for concern in the event of subsequent, more intense storms, particularly during summer vacation periods. They include (1) lack of effective procedures to prevent premature reoccupation of evacuated areas, (2) failure to assess the safety of buildings used as public hurricane shelters, (3) delays in recommending evacuation after receipt of hurricane warning, (4) lack of alternatives to evacuation on developed barrier islands that are nearing the threshold of evacuability under current warning conditions (e.g., vertical refuges, building capacity controls, (5) disputes among local leaders and officials about proper authorization of community evacuations, and (6) inadequate resources for speeding the removal of debris from urban streets.

5

CONCLUSIONS AND RECOMMENDATIONS

Diana highlighted some well-known hurricane protection issues and some newly emerging problems. Like the most recent hurricanes that have struck the United States, such as Iwa and Alicia, this was a weak storm that nonetheless inflicted significant economic losses (National Research Council, 1983a, 1984). Unlike those hurricanes, it struck an area that is thought to be relatively well prepared to withstand such storms.

METEOROLOGY AND COASTAL PROCESSES

Diana will probably be remembered as the storm that threatened to be another Hurricane Hazel. While not a really severe hurricane when it went inland, it was still intense enough to cause considerable damage.

The forecasting and warning systems functioned efficiently, and the forecasts were quite accurate considering the great difficulty of forecasting erratically moving hurricanes. Nevertheless, several problems were highlighted. The various objective forecast systems gave quite diverse forecast results. Similar findings were noted with respect to Hurricane Alicia (National Research Council, 1984). Research is needed to improve forecast techniques, but the need to overcome data deficiencies is even more pressing, especially for wind measurements at middle and upper levels of the atmosphere in areas around hurricanes. Likewise, the lack of good surface wind information in high-wind sectors of hurricanes as they approach and cross coasts hampers studies of ways to ameliorate hurricane damage. Finally, it is recognized that the state of the art in forecasting hurricane intensity is weaker than for forecasting hurricane motion.

- Recommendation Greater use should be made of Omega dropwindsondes or similar devices for obtaining improved data on wind speeds at various elevations around hurricanes.
- Recommendation Continued experiments should be conducted with VAS satellite retrievals to determine if constant pressure maps can be constructed near hurricanes to provide indications of the wind flow in the middle layers of the atmosphere.

o Recommendation High-quality anemometers with recorders and emergency power should be distributed along coasts prior to hurricane landfall.

o Recommendation Research on forecasting the intensity of hurricanes, as distinct from their movement, should be accelerated.

o Recommendation Forecasters should investigate the feasibility of attaching confidence levels to intensity forecasts.

One of the major constraints in determining the extent and role of storm waves and surges is quantitative data. Since gauges fail with predictability when needed most--during storms--reliable information is seldom available on open-coast surges that could be compared with model predictions. Secondary information such as storm debris lines can only provide an indication of the peak surge. A time history of the storm surge, indicating the duration of particular levels, is paramount in applying analytic techniques to evaluate beach and dune erosion (Kriebel and Dean, 1984).

What is clearly needed are simple, inexpensive, portable wave/tide gauges that can be set along the coast before hurricane landfall and will function faithfully during extreme conditions. Not only would these gauges provide accurate information on individual storms, but the data could be used to calibrate the output from numerical models and permit the refinement of frequency-magnitude relationships for better long-term predictive capabilities.

o Recommendation The National Ocean Service of the National Oceanic and Atmospheric Administration should coordinate with the U.S. Army Corps of Engineers and other relevant agencies or organizations to ensure the procurement and deployment of portable wave/tide gauges in advance of a hurricane.

BUILDINGS, STRUCTURES, AND LIFELINES

Since the design wind speed does not appear to have been exceeded and there was only a small storm surge, structural failures in engineered buildings are presumably attributable to serious underdesign or inaccurate building code specification of wind effects on buildings. The few engineered buildings that were affected by Diana performed well except for the Xanadu II condominium in North Myrtle Beach, South Carolina. This building suffered severe cladding damage at wind speeds less that 60 mph. Its unusual shape may have induced suctions greater than those specified in the building code. Nevertheless, the cladding system used was probably capable of carrying only about 25 percent of the load it should have in order to satisfy the building code with a reasonable degree of safety. Although loss of these cladding units had little effect on the structural integrity of the building, their failure resulted in serious water damage.

The performance of preengineered metal-framed buildings was generally good, although they were not severely tested. Apart from travel trailers, virtually all mobile homes were well tied down. Many performed satisfactorily because of this and the small storm surge. However, the fact that several suffered severe damage without turning over indicates an inadequate structural system.

Many of the three- and four-story condominium units were probably marginally engineered. Although they do not come under the North Carolina Residential Building Code, many of the techniques for wind-resistant construction contained in that document are used in the construction of these multistory wood structures. Most performed well during Diana, but two under construction in Carolina Beach suffered shear failures when substantially complete. A subsequent structural analysis and wind tunnel test suggested that some of these structures might have been fairly close to failure and would lack sufficient shear resistance to withstand design wind forces. Very few engineers have experience in designing multistory wood structures, and very little is known about their performance in extreme wind conditions. Fortunately, fire regulations limit the use of this form of construction to three occupied stories. They can effectively be four stories high and stand as much as 50 ft above the ground, however, because an unoccupied story is required for flood protection.

It is in the area of domestic and other nonengineered structures that the enforcement of prescriptive building codes and standards can have the greatest effect. Adherence to these codes should result in structures with factors of safety not less than compliance with a code based on an engineering analysis. One should not therefore have expected structural failures at the wind speeds experienced in Hurricane Diana. On the whole, buildings meeting the North Carolina Uniform Residential Building Code performed well, and their superior performance in comparison with buildings predating the code was clearly evident. Failure of structures that postdate the code could generally be attributed to negligence or misunderstanding of the provisions.

A large roof overhang is a highly undesirable feature in a building subject to high winds, but houses in the South commonly incorporate one and sometimes two covered porches. The residential building code is vague in its requirements for securing porch overhangs. One survey (Rogers, 1985) indicated that over two thirds of all structural damage in Hurricane Diana could be attributed to failure of connections between porch columns and roofs. Very often this resulted in partial removal of main roof sheeting as well as loss of porch roofs, followed by serious water damage to the contents and interiors of buildings.

For several years the Standard Building Code has had an appendix governing design of masonry walls for hurricane-force winds but no specific recommendations for timber construction. In 1984 a separate standard was issued covering wood stud, brick, and concrete block walls in hurricane-prone areas (Southern Building Code Congress International, 1984). Although restricted to walls nominally 8 ft high with roof overhangs less than 4 ft, it represents a considerable improvement over previous provisions. Since the clauses in the document are deemed to satisfy requirements of the legal code, its use should make enforcement easier in areas where the Standard Building Code has been adopted. Good building inspection is essential to ensure that buildings are in conformance with requirements.

In spite of the generally satisfactory performance of North Carolina residences that were built in conformance with current codes, it must be remembered that wind speeds did not reach the design level, nor were buildings subject to the storm surge or wave action that typically accounts for significant hurricane damage. Nevertheless, in view of the extensive damage caused by Hurricane Alicia under similar conditions in an area with poor building controls (National Research Council, 1984; Rogers et al., 1985), it is clear that there are advantages to be gained from the use of a specific and easily understood code for nonengineered buildings. North Carolina's experience with Hurricane Diana should encourage the use of similar codes in other hurricane-prone areas of the country.

In damage surveys, very little attention is generally paid to superficially minor problems such as loss of roof shingles. Unfortunately, hurricane winds are usually associated with torrential rain--up to 14 in. in 24 hours during Hurricane Diana. Loss of shingles and even poorly designed roof vents and windows will permit water penetration and subsequent interior damage. Because of the large number of buildings affected by this type of damage, a substantial proportion of the total loss from storms may be due to these failures, particularly where strong building codes and good building practices have significantly reduced the risk of serious structural damage. This was true in Hurricane Diana, where many buildings lost roof shingles or waterproof membranes and there were many reports of water penetrating through roof vents (Rogers, 1985).

o Recommendation Building inspectors should pay careful attention to the cladding systems used in engineered buildings.

o Recommendation Every effort should be made to discourage large roof overhangs in hurricane-prone areas. Failing this, more specific recommendations for anchoring overhangs should be contained in building codes.

o Recommendation Serious consideration should be given to ensuring that complete roofing systems--not just roof structures--are capable of resisting design wind speeds and that vents and windows do not leak under driving rain.

As evidenced by the limited damage, relatively few changes are needed in the design, installation, or operation of lifeline systems.

o Recommendation Screen nets or grids should be placed around inlets and outlets of drainage pipes associated with dams and embankments.

o Recommendation Elevated water tanks should be anchored by cables or stays.

EMERGENCY MANAGEMENT

The performance of emergency preparedness and response systems during Diana varied from adequate to excellent. Nonetheless, weaknesses that may foreshadow future difficulties were evident. In particular, these include (1) unsatisfactory provisions for preventing premature reoccupation of evacuated areas, (2) failure to plan for circumstances that may prevent full evacuation of barrier islands, (3) inadequate measures for ensuring the safety of emergency shelters, and (4) confused lines of authority in some local municipalities.

o Recommendation Local emergency managers should institute improved procedures for controlling access or reentry to barrier islands and other hazard zones once these have been evacuated. Reentry should be restricted at least until a threatening storm has entirely crossed the coastline and begun to dissipate over land. Prior to a storm's arrival, residents and occupants might be issued passes that allow readmission to evacuated areas on the advice of safety officials. These or similar procedures should be adopted by municipal police and fire departments, the National Guard, and others charged with direct supervision of public safety. They should also be closely coordinated with the National Weather Service and among all municipalities within the same county as well as adjacent municipalities across county lines. Procedures and criteria used in connection with the reopening of evacuated areas should be widely published.

o Recommendation The National Weather Service should carefully review policies and procedures concerning the public release of forecasting information to ensure that disagreements and uncertainties among forecasters are appropriately and adequately communicated to populations at risk.

o Recommendation The Federal Emergency Management Agency, the U.S. Army Corps of Engineers, state and local emergency managers, county planning agencies, and others responsible for programs that affect the evacuation of barrier islands should develop alternatives to the predominant existing system of road transportation to safe mainland locations. They might consider, among other options, vertical refuges in situ and restrictions on new development that will add to the evacuation burden.

o Recommendation Federal, state, and local emergency management agencies should clarify and strengthen evacuation decision making to avoid confusion about the roles, responsibilities, and rights of different governments and agencies.

o Recommendation County engineers, building inspectors, emergency managers, and other relevant local authorities should inventory and survey all potential public hurricane shelters to determine that they are located outside flood hazard areas and are capable of withstanding major hurricane-force winds without sustaining serious damage.

o Recommendation In conjunction with county and state emergency managers, all local municipalities should clearly define and publicize lines of authority and commensurate responsibilities for recommending or ordering the evacuation of barrier islands.

HAZARD MITIGATION

No more than a handful of buildings suffered large-scale damage. Most of these either (1) predated the introduction of strong building regulations, (2) were shoddily constructed, (3) were in the process of being erected, or (4) occupied sites that had already suffered serious undermining and erosion. With the possible exception of agriculture, the bulk of the $80 million in estimated losses appeared to have been made up of many small-scale losses. Few people suffered catastrophic losses in the conventional sense. Typically, there was damage to trees and shrubbery; exterior lighting, signs, shingles, and glazing; and overhead electric power lines; there was also limited loss of beach sand. As coastal populations continue to grow and as development fills in areas of intermediate hazard, landward of the outer ranks of coastal structures, even small and moderate storms threaten to inflict substantial losses of these types. At present, mitigation measures for hurricanes emphasize the reduction of major losses to homes and businesses. Attention also needs to be paid to the problem of reducing small individual losses that produce large aggregate, community-wide totals.

- Recommendation Communities at risk should plan to reduce routine but costly storm damage to trees, beaches, boardwalks, overhead power lines, and outdoor architectural features that existing mitigation programs overlook. This may include such measures as (1) planning for the removal of debris, (2) adopting and enforcing stricter design and construction standards for signs and outdoor lighting, (3) integrating maintenance dredging and beach nourishment programs, (4) creating a reserve fund for the restoration of beaches and boardwalks, (5) ensuring the burial of electrical and telephone lines, and (6) improving the care of vegetation.
- Recommendation In concert with state floodplain management programs, state coastal management programs should undertake and publish detailed postdisaster analyses of sample public and private properties to determine the effectiveness of existing mitigation measures and to identify needed improvements. Some of this work is already being done by FEMA's interagency hazard mitigation teams and by the Committee on Natural Disasters, but many damaging storms are not examined because emphasis is placed on major disasters.
- Recommendation Federal and state agencies with responsibilities for funding, insuring, constructing, operating, or otherwise managing facilities or activities on developed barrier islands should explore the potential for mitigating chronic and acute storm damage by selectively reducing or eliminating these responsibilities. This might involve extension of the Coastal Barrier Resources Act of 1982 to include developed coastlines.

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