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Hurricanes Dennis and Floyd: Coastal Effects and Policy Implications

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Figure 1. Erosion on Oak Island, North Carolina by Hurricane Floyd in 1999. Pilings on the house and exposed, broken septic tanks lining the beach indicate that the beach profile was lowered approximately 1 m during the storm. Septic tanks are emplaced with drain fields above the water table, which limits their location in nearshore environments. As an example of the range of impacts of human development in the coastal zone, before Floyd the recreational beach was situated directly above these septic systems.

ABSTRACT

Tropical systems Dennis and Floyd impacted eastern North Carolina in 1999, the fourth and fifth storms in three years to make landfall in this area. All five storms were very similar in strength (wind speed); however, the effects on the coast were quite different. In addition to absolute storm strength, morphological changes to the natural environment were controlled by the forward speed of the storms, orientation of the shoreline relative to storm track, underlying geology, impacts of recent storms, and associated rainfall. Damage to buildings was a function of the placement of structures with respect to the shoreline and the removal of weaker buildings by previous storms. On the basis of these observations, we recommend a new Hurricane Impact Scale, which will allow prediction of possible storm impacts and comparisons of coastal impacts in other hurricanes.

Each additional hurricane demonstrates that our society does not have a forward-looking plan for dealing with coastal storms. Instead, we typically repair and rebuild in place, and continue the upward spiral of property damage in storms. Although the dollar amount of property damage will be low from these storms, the public must bear the cost of cleanup and repair of infrastructure.

INTRODUCTION

The probability that a hurricane will make landfall at any given point along the coast in any one year is low, and the even lower probability of a great hurricane (category 3, 4, or 5) makes such an event seem extremely unlikely. But low probabilities give a false sense of security, because the lesson of hurricane history tells us that in the lifetime of a building such a storm is almost a certainty. Furthermore, the occurrence of a hurricane one year does not reduce the likelihood that a similar storm will strike again the next year.

The coast of North Carolina was struck by two hurricanes in 1996 (Bertha and Fran). It happened again in 1999. Hurricane Dennis impacted the coast for several days, from August 30 to September 4. Hurricane Floyd made landfall on September 16, causing record flooding across most of eastern North Carolina and damage to shoreline structures in some places (Fig 1). These were the fourth and fifth storms to strike the North Carolina coast in the past three years (Fig. 2). Local meteorologists and the popular media described the first of these (Bertha) as a 50-year storm—a storm that would be expected to recur once every 50 years. All five storms in this three-year period were of comparable strength and had varying coastal impact. Obviously, our concept of a 50-year storm may need some adjustment. It is also clear that despite recent improvements in hurricane forecast models, long-term forecasting is still difficult if not impossible, as demonstrated by both 1999 storms. We describe here the geological impact of these two storms in North Carolina, and we discuss our views on the coastal zone management lessons to be learned and the need for a new scale to communicate predicted and observed coastal storm impacts.

HURRICANE DENNIS

Dennis tracked up the U.S. East Coast as a category 3 hurricane on the Saffir-Simpson scale of hurricane intensity, stalling off the Outer Banks of North

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Hurricanes *continued from p. 1*

Carolina on Monday, August 30. The storm then reversed course, remaining off North Carolina until it made landfall across Core Banks on Saturday, September 4 (Fig. 2). By that time Dennis had weakened to a tropical storm (sustained winds less than 119 km/h).

Hurricanes usually move ashore quickly, minimizing the time available to erode beaches, but Dennis stayed offshore for several days, producing large waves much like a stalled winter storm or nor'easter. In this century, the storm that caused the most damage on the Outer Banks was the Ash Wednesday storm of 1962, a nor'easter that remained stationary for three days at the time of spring tides. Tidal amplitude on the Outer Banks is small (less than 1 m) but large enough to cause increased dune erosion and inland penetration by overwash when storms arrive at high tide. Waves from Dennis impacted the shoreline of the North Carolina Outer Banks through at least a dozen high tides, a major factor in island response to the storm. Even though damage to structures along the shoreline was not extensive, the long duration of Dennis may have caused as much coastal erosion and shoreline retreat as a category 4 or higher hurricane.

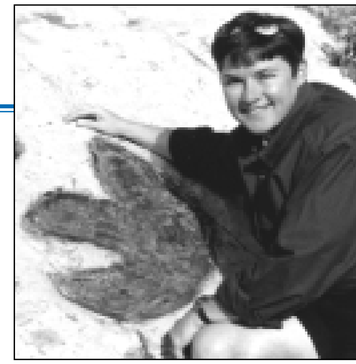
On narrow and undeveloped Core Banks (Fig. 2), part of the Cape Lookout National Seashore, large numbers of narrow overwash fans were produced as storm surge flooded parts of the island and storm waves rolled ashore and across the island through dune gaps and eroded dunes. In this way, sand was actively deposited on the island (Fig. 3). A few of the overwash fans extended into the sound behind the island. Barrier island migration is a complex process primarily driven incrementally by storms during times of rising sea level (Leatherman et al., 1982; Nummedal, 1983; Leatherman, 1983a, 1983b). Pilkey et al. (1998, p. 44–47) described barrier island migration with North Carolina examples as a three-step process. Barrier islands migrate landward by: (1) shoreline retreat on the open ocean side, (2) elevation of the island by the addition of overwash sand, and (3) movement of the island's soundside shoreline landward by extension of the overwash fans into the sound. All of these processes were evident on Core Banks following Hurricane Dennis. In this fashion, Core Banks took another small step landward and up the coastal plain during the current sea-level rise.

Along Hatteras Island (Fig. 2), within the Cape Hatteras National Seashore, several small communities are connected by a lone road, the two-lane, blacktop NC Hwy 12. Overwash sand covered the road in many places and was quickly cleared by highway crews following the storm; most of it was moved to the nearby beach. A <0.5 km section of the road north of Buxton that was entirely destroyed during the hurricane was rebuilt within three days. We are trying to convince the North Carolina Department of Transportation to leave the overwash sand in place and rebuild the road, perhaps with gravel. This would allow the island in the National Seashore to function naturally, and the road elevated by the addition of overwash would be subjected to less frequent storm flooding, reducing damage in future storms and saving taxpayer dollars.

In the 1930s, as part of a Civilian Conservation Corps project during the

Dialogue

Sara Foland, CEO



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At Dinosaur Ridge near Morrison, Colorado.

The Year Past and the Year Ahead

> To tend, unfailingly, unflinchingly, towards a goal is the secret of success.
>
> *—Anna Pavlova*

We are completing an exciting year at GSA and looking forward to a new year, a new century, and a new millennium. Here, I review what GSA has accomplished and tell you about some of my goals for the next 12 months and the next several years.

In July, the headquarters staff completed a significant reorganization, to align our human and fiscal resources with the annual goals that were defined from the five-year strategic plan. In the next several issues of *GSA Today,* we will discuss the strategic plan with you in greater detail and highlight progress and new directions. The four new functional areas at GSA headquarters are Science, Education, and Outreach—focused on education and public policy; GSA Enterprises—our revenue-generating activities; Member Services—the interface and service center for members; and Infrastructure Services and Support—for all our in-house needs in Boulder.

With the reorganization of our Science, Education, and Outreach group, we envision a new direction in education. We are expanding our focus to include K–12, undergraduate, and graduate levels. A new Education Science Officer position has been approved, and a national search committee is being formed. Robert Ridky, University of Maryland, will chair this committee.

All programs and services that directly support members are located within Member Services. A new Member Service Center will provide real-time service for all our members and our customers. On January 3, 2000, you can reach this team at our new toll-free number, 1-888-443-4472, to buy a book, change your address, register for a section or annual meeting or get a question answered. To gather more information about members, we initiated a comprehensive general membership survey in November 1999. A sample set of 3,300 was selected from our total membership of 16,000.

At this year's annual meeting we received 85% of the 2,942 abstracts electronically; this is the highest electronic submission rate and the largest number of abstracts ever for GSA. We had 6,389 registrants at our meeting in Denver, making it one of the three largest GSA annual meetings. Planning is now underway for the first GSA global meeting, scheduled for June of 2001. This joint venture with the Geological Society in London will be held in Edinburgh, Scotland. Meetings are one part of GSA Enterprises; publications are the other part. In 2000, a feasibility study on electronic publishing options will begin.

A new budgeting process was reviewed with the Investment and Budget committees at the 1999 GSA Annual Meeting and will be used in the preparation of our fiscal year 2000 budget. This new model balances growth of our investment portfolio with prudent spending. Growth of the portfolio will be ensured first, to protect the long-term future of GSA. To provide program review and prioritization, a new committee, the Programmatic Overview Committee (POC), was formed. At the committee's first meeting, the GSA staff reviewed the 166 current programs. This review allowed our leadership to look at GSA as a whole, not just piece by piece. The overall success of the first program review led to the POC becoming a standing committee, which will meet annually at the spring Council meeting.

To accomplish the array of objectives in our strategic plan, GSA must pursue strategic partnerships. These joint ventures will enlarge GSA's sphere of influence and help us to reach our goals in more timely and cost-effective ways. Currently, we are investigating joint ventures for global meetings, online publications and digital archive creation, integrative science, and student programs. Strategic alliances have been formed with the USGS, National Park Service, National Forest Service, AGI, and the Geological Society (London). All 23 of our associated societies are reviewing new partnership opportunities for 2000 and beyond.

In the next year, I look forward to shifting my perspective from internal operations to external partnerships. Adopting a more external view will allow me to work on strengthening our existing partnerships and exploring new ones—aiding in the expansion of GSA's sphere of influence. I am excited about the future and very pleased with the progress to date. To get a chance to chat with you in 2000, I will attend all the section meetings in the spring. Roundtable discussions will be scheduled to discuss GSA and gather your insights and hopes for the future, and to learn how GSA can help you attain your goals.

Enjoy the New Year!

Hurricanes *continued from p. 2*

depression, a large frontal dune line for erosion control was constructed from the North Carolina–Virginia line to the western end of Ocracoke Island (Stick, 1958, p. 250). The presence of the dune encouraged beachfront development in areas previously routinely overwashed during storms. Now the artificial dune line has large gaps due to shoreline retreat, and hundreds of buildings are exposed to storm processes, especially north of Oregon Inlet in the old towns of Nags Head, Kitty Hawk, and Kill Devil Hills (Fig. 2). In these communities, Dennis covered the roads with sand and debris and eroded beneath numerous houses elevated on pilings. These communities are particularly prone to flooding because the interior of the island is at a lower elevation than the oceanfront and because the primary dunes, which would have afforded some measure of protection from storm surge and waves, have been eroded. The seaward-facing part of the island communities is a landward-sloping surface of coalesced overwash deposits. Storm surge and waves easily overtop the overwash and flood the island interior. Thus, for the fifth time since 1990, the seaward-most, three-block area of the towns was flooded by ocean water trapped behind the higher elevation beachfront. Because the old dune cannot be replaced without removal of the first row of houses, a politically difficult thing to do, these communities face more flooding from future storms.

An aerial flyover of the impacted area after the storm indicated that the amount of dune and beach erosion varied considerably along various shoreline reaches. We believe that the differences in shoreline impact may have been strongly controlled by offshore geology; in particular, Kinnakeet and Wimble shoals partially protected the towns of Avon and Salvo, respectively. Geologic framework and barrier island dynamics are discussed by Riggs et al. (1995). Overall, only a small number of buildings were destroyed by Dennis, because the winds were sub-hurricane strength and storm surge was probably only about 0.5–1 m. Sand was eroded from beneath many buildings, and some, partic-

Hurricanes *continued on p. 4*

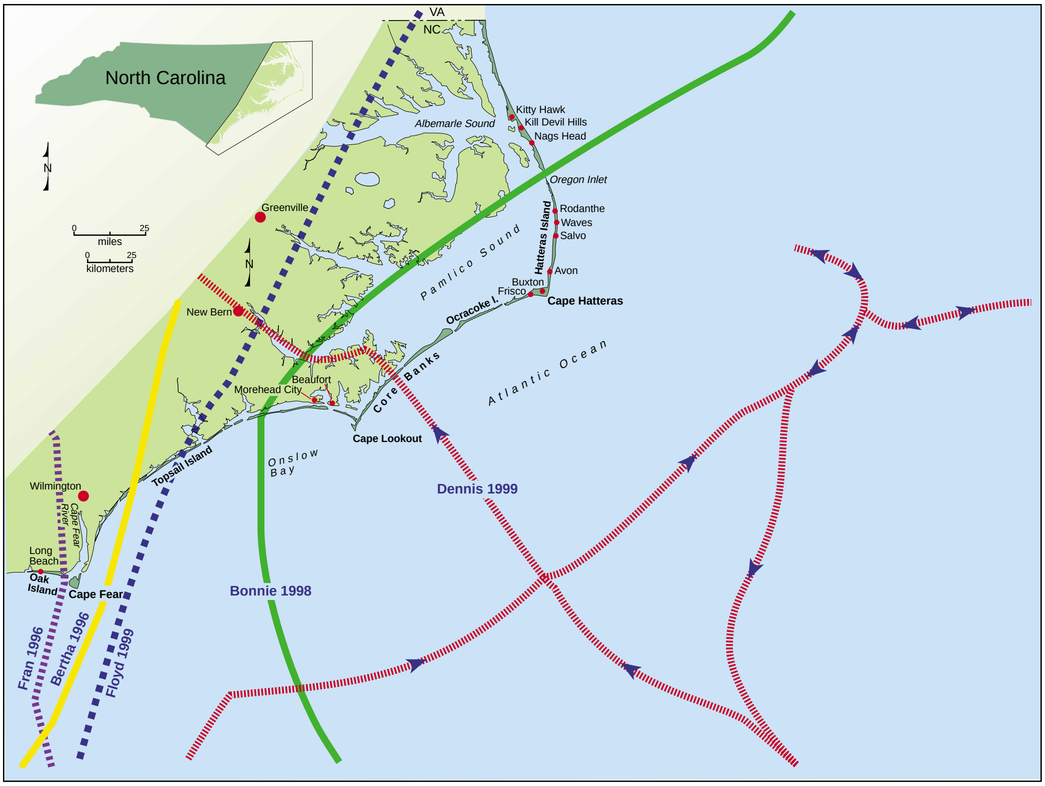

Figure 2. Eastern North Carolina and tracks of the five hurricanes affecting the North Carolina coast from 1996 to 1999. Notice the similarity in landfall locations, especially of Fran, Bertha, and Floyd, and the erratic path of Dennis. The Outer Banks of North Carolina stretch over 280 km from the Virginia line to below Cape Lookout.

Hurricanes *continued from p. 3*

ularly in Rodanthe, were left stranded seaward of the high-tide line.

Immediately after the storm, North Carolina Governor Jim Hunt declared that federal funds for a beach nourishment project, long in the planning stage, were needed immediately. The project as planned is a small one, however, and probably would not have prevented flooding and other damage. The speaker of the North Carolina State Senate, in whose district most of the hurricane damage occurred, stated that the shoreline was in the "worst erosive shape possible" prior to the storm, and that beach and road-building money was needed immediately. His view is undoubtedly shaped by the fact that more buildings than ever were exposed to the storm, the inevitable consequence of decades of shoreline retreat occurring simultaneously with intensive beachfront construction of cottages and motels. The Outer Banks are perhaps the most naturally dynamic developed barrier island chain in North America, but as is true everywhere, politicians respond with crisis-driven maintenance of the status quo, thereby treating beachfront development in similar fashion to inland development at higher elevations. Our view is that due to a lack of planning for sensible post-storm action, an opportunity is missed to relocate buildings and roads back to safer locations following storms such as Dennis. The Outer Banks are a high-hazard setting for development. There is high wave energy here due to a narrow continental shelf (Hayes and Sexton, 1989). In addition, high storm frequency and ongoing sea-level rise will mean that maintenance of the shorefront in its current location will prove ultimately impossible.

One building, the six-story Comfort Inn at Whalebone Junction in Nags Head (Fig. 2), now resides on the beach, having lost its swimming pool. This is an old structure, probably the first high rise built on the Outer Banks. The hotel was originally built well back from the beach. Shoreline retreat of about 1 m/yr has caught up with the hotel. Because seawall construction is illegal in North Carolina, a politically difficult situation faces the state's coastal managers. We believe that this building represents a landmark in the state's efforts to preserve beaches for future generations. If a variance in the regulation is granted, North Carolina's anti-shoreline armoring regulation is doomed, as is the future quality of recreational beaches.

HURRICANE FLOYD

Hurricane Floyd was a much larger and more powerful storm than Hurricane Dennis, although it was not as strong and was smaller than Hurricane Hugo, which struck the South Carolina Coast in 1989. After causing serious wind damage in the northern Bahamas, the storm threatened the east coast of Florida with maximum sustained winds of 249 km/h (category 5 is >249 km/h). As it tracked to the north, it gradually lost wind velocity, coming ashore in southern North Carolina, south of Cape Lookout as a strong category 2 storm with maximum winds around 150 km/h. The hurricane dumped more than 50 cm of rain on parts of eastern North Carolina where the ground was already saturated from the passing of Hurricane Dennis. Floyd followed a classic path, curving up the U.S. East Coast, leading to the largest evacuation in U.S. history, more than 2 million people in Florida, Georgia, South Carolina, and North Carolina. Track forecast models fared much better than in Dennis, but model uncertainty allowed for possible landfall in Florida, Georgia, and South Carolina before the storm went ashore near Cape Fear, North Carolina (Fig. 2).

The beachfront damage, the primary focus of this paper, has received relatively little attention in the North Carolina and national media because the most damaging aspect of Floyd was riverine flooding in eastern North Carolina and New Jersey. Flood levels in several North Carolina counties exceeded the 100-year recurrence interval level and were the highest ever recorded. Two interstate highways (I-40 and I-95) were blocked for several days and two universities (University of North Carolina at Wilmington and East Carolina University in Greenville) were closed because of power loss, emptying students from dorms into communities cut off in all directions by river waters. This type of storm presented major difficulties for those who evacuated from the Outer Banks, which turned out to be largely unaffected by Floyd. One person left Ocracoke Island (Fig. 2) only to require rescue off an inland roof top by helicopter.

On the coastline, Long Beach, North Carolina, on Oak Island (Fig. 2), was hit the hardest. This old community has a history of disruption by hurricanes. It was thriving prior to 1954, when 300 out of 305 buildings, properly built well back from the beach, were destroyed or moved off their foundations by category 4 Hurricane Hazel. The buildings were rebuilt, and the shoreline, in its inexorable, 0.5–1 m/yr landward creep, caught up with the buildings. During Hurricane Floyd, about 240 beachfront homes (more than half of the oceanfront homes in the community) were destroyed or made uninhabitable, largely due to wave action on top of a 1.5–2.5 m storm surge. Before the storm, it was clear that the extensive damage was entirely predictable, because this was a highly vulnerable community (Pilkey et al., 1998). A large vertical scarp was formed in many places at the back of the beach on Long Beach. The scarp cuts into old wetland sediments imbedded with tree stumps—another clue that this barrier island was sand-poor and vulnerable before the storm. Previous work has shown that the age of tree stumps exposed on the beach varies along Oak Island, ranging from about 3.8 to 1.8 ka (Griffin et al., 1979; unpublished data of Cleary). This is further evidence of the island's erosive history even before the storm.

On heavily developed, low-elevation, narrow Topsail Island (Fig. 2), most of which was extensively damaged by Hurricanes Bertha and Fran (occurring within eight weeks of each other in 1996) building damage was much less than on Long Beach. Local officials attributed this to the fact that the poorly constructed buildings had been removed by the earlier storms. In addition, the storm surge from Floyd was 0.3–0.8 m less than during Fran. Instead of a dune scarp, the northern part of the island had the appearance of a large smooth sandbar, because almost the entire island was covered by a sheet of overwash sand. The island infrastructure, roads, power and phone lines, and septic and sewer systems were largely destroyed after having been replaced by federal funding after Fran in 1996. In spite of the lack of loss of private property, the federal recovery costs to replace infrastructure on this island will be large. At least two and possibly three of the temporary inlets opened by Fran were reopened in Floyd. Some houses built after Fran in the throats of the former inlets were washed under but survived. Strong evidence was noted of erosion caused by channelization of storm-surge ebb (the seaward return of the storm surge as the storm moved away; Fig. 4). Along much of Topsail Island, the only frontal dune was an artificial one, constructed largely from sand bulldozed from the beach. Much of the dune disappeared in Floyd (Fig. 5), making up a large part of the overwashed sand on the island. At the northern end of the island, the dune has been replaced at least five times in the 1990s.

Figure 3. Core Banks, North Carolina, was almost completely overwashed by Hurricane Dennis as the storm stalled offshore for several days. With each high tide, storm-surge flooding and storm waves washed sand onto and, in some cases, completely over the island. Storms drive barrier island migration during rising sea level. Overwash deposits are a primary way in which island elevation is built up and the soundside shoreline is incrementally moved landward.

NEED FOR A NEW HURRICANE IMPACT SCALE

After Dennis and Floyd, as well as several previous hurricanes that have affected North Carolina over the past several years, it is clear that coastal geologists must do a better job of conveying to the public the coastal geomorphological effects of these storms. The public hears about the Saffir-Simpson hurricane scale and has a good idea of the relative strength of storms. Saffir-Simpson is a scale of categories 1 (120–152 km/h) to 5 (>249 km/h), and was originally developed as a hurricane damage potential scale (Simpson, 1974). Although the scale is satisfactory for describing the absolute strength of a hurricane in the open ocean, it is less satisfactory in describing the effect of a hurricane on the shore during landfall. Geologists understand that the actual impacts of any given hurricane on the coast will vary depending on several geologic and meteorologic factors including, but not limited to: (1) the absolute strength of the hurricane (wind speed), (2) the size of the storm (radius of maximum winds), (3) forward speed of the storm center (faster equals higher storm surge), (4) track of the storm relative to orientation of the shoreline (perpendicular approach means higher storm surge, low-angle approach means greater area affected), (5) storm duration (relatively short in most hurricanes), (6) offshore and onshore profiles (major control on storm surge), (7) planview shape of the shoreline (major control on storm surge), (8) underlying island geology including sand supply (can control shoreline erosion and overwash, see Riggs et al., 1995; Cleary, 1997), and (9) recent storm history (one storm removing the protective dunes, setting up the shoreline for greater damage to structures in a subsequent storm). Because the Saffir-Simpson scale does not consider these local and regional controls on coastal response to hurricanes, we believe that a new scale emphasizing hurricane impact is needed.

Hurricanes *continued on p. 6*

Figure 4. When storm surge water flows back to sea, either by the force of gravity alone or when driven by offshore-blowing winds, an erosive ebb current may be generated with a potential for intense scouring of unconsolidated material. Often, structures in the path of such scouring are undermined and may topple. In this example from Topsail Island, storm-surge ebb scouring has eroded a channel at least three feet deep. The house in the center of the photo survived because the scour channel divided and flowed on either side of it.

Figure 5. Immediately after Hurricane Fran in 1996, an artificial dune was built along the shoreline of North Topsail Beach (the northeastern one-third of Topsail Island) for protection of the only access road. The dune was almost entirely removed by Hurricane Floyd in 1999, and the sand was redistributed as washover deposits on the island.

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We are developing a Hurricane Impact Scale (HIS) that could be used pre-storm to warn residents of coastal communities of potential coastal impacts and post-storm to compare events. The criteria to be considered for the new HIS are: (1) maximum elevation of the storm surge (the elevated water level associated with the passage of a hurricane), (2) storm surge spread (how large an area has been impacted by higher water level), and (3) wind speed.

The HIS will reflect the understanding that all storms of the same Saffir-Simpson category do not have the same coastal effects. Even identical storms striking the same shoreline reach may have differing impacts. For example, storm surge from Hurricane Floyd was predicted and reported to be 4.6 m on Long Beach but was in actuality between 1.5 and 2.5 m. The 4.6 m estimate was based on the Saffir-Simpson scale for a standard category 4 hurricane approaching perpendicular to the shore across a continental shelf of known width and shape. Hurricane Floyd, however, came ashore at Cape Fear, at which point the most deadly northeast quadrant was out at sea and the continental shelf region used to generate storm surge was different than that of the predictive model. Because of the uncertainty inherent in hurricane track forecast models, it is impossible to predict exactly where a hurricane will make landfall, and thus it is impossible to predict exactly what the coastal impacts will be. The Hurricane Impact Scale will provide a larger range of categories than the Saffir-Simpson scale, and we envision using the two scales in conjunction. Taking the meteorological characteristics of the storm and using the criteria above, we will predict, for example, that a given storm will have an HIS category of 9 if it stayed on one track but 13 if it veered to another track. Thus, we will predict a range of HIS categories for a single storm, depending on the forecast range of landfall tracks. Post-storm investigations will provide a single HIS for a given storm, and allow easy comparisons to other storms.

CONCLUSIONS

Tropical systems Dennis and Floyd will not go down in history as significant coastal events. Dennis will be remembered for its erratic path, and Floyd will be remembered for its record-setting and devastating inland flooding. More significant is the opportunity to compare effects of these two and three other storms (Bertha and Fran, 1996; Bonnie, 1998) of similar strengths impacting essentially the same area in just three years.

Hurricanes and other coastal storms play an integral role in barrier island migration during times of rising sea level. In the larger sense, hurricane-driven oceanside erosion and deposition of overwash sand on barrier islands and completely over them are important steps in the barrier island migration process and were well illustrated by these storms. However, the smaller-scale ocean-shoreline morphological changes, and especially the interaction between storm processes and human development, varied greatly in each of the five storms. This complex interaction is dependent on many geomorphic and geologic factors in addition to the meteorological factors of storm strength, size, and forward speed. Ongoing studies are assessing which factors are the more important.

There are two important coastal policy lessons to be learned from these recent storms. First, we do not have a forward-looking plan for dealing with coastal storms. The typical response is cleanup and complete rebuilding, maintaining the status quo. Coastal planning must incorporate storms as part of the plans. We must learn from nature and not rebuild damaged structures and infrastructure in place, nor with the same design. Little planning effort goes into learning how to best rebuild after a storm. Witness the artificial dune line on northern Topsail Island or NC Hwy 12 near Buxton which are damaged and rebuilt over and over again. The second policy lesson is that even though none of these storms had a high dollar amount of property damage at the shoreline, and will thus be considered largely as non-events, the public still must pay to repair infrastructure. Even if not a single house was lost on Topsail Island, for example, the cost to remove all the sand from the roads, rebuild the roads, repair the electrical supply system, and rebuild the frontal dune will be great. Insured costs to homeowners is the damage amount typically reported, but the cost of repairing infrastructure is not an insured cost, and it is borne by the public.

The legacy of Bertha, Fran, Bonnie, Dennis, and Floyd may well be that they allowed detailed comparisons over a relatively short time frame in a relatively compact geographic area. The need for a new Hurricane Impact Scale grew out of these comparisons. A better understanding and ability to predict storm-process interaction with development, and a greater ability to communicate these predictions to the public, will aid in coastal management decisions on zoning and land-use planning. As coastal population continues to swell, coastal geologists must take a more active role in coastal management. Immediate post-storm observations such as those presented here will remain an important tool.

ACKNOWLEDGMENTS

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