Reducing Vulnerability in Five North Carolina Coastal Communities:

A MODEL APPROACH FOR IDENTIFYING, MAPPING AND MITIGATING COASTAL HAZARDS

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INTRODUCTION: OVERVIEW AND FINDINGS

"In recent years the coastal area has been subjected to increasing pressures which are the result of the often-conflicting needs of a society expanding in industrial development, in population, and in the recreational aspirations of its citizens. Unless these pressures are controlled by coordinated management, the very features of the coast which make it economically, esthetically, and ecologically rich will be destroyed. The General Assembly therefore finds that an immediate and pressing need exists to establish a comprehensive plan for the protection, preservation, orderly development, and management of the coastal area of North Carolina."

- NC Coastal Area Management Act of 1974

The above excerpt from North Carolina's Coastal Area Management Act was written in 1974. Unfortunately, it is just as true today as it was over 25 years ago. In light of North Carolina's burgeoning coastal hazard management problems, it has become clear that new and innovative approaches towards coastal hazard mitigation are needed.

Although traditional approaches to property damage mitigation must continue to be applied, the purpose of this report is to promote the recognition, understanding and application of mitigation approaches based on the physical processes active within the North Carolina coastal environment.

The goal of the report is to encourage all coastal communities to develop a coastal processes approach to property damage mitigation using a methodology that combines traditional and innovative approaches towards coastal hazard recognition, mapping and mitigation. The following points are central to this goal:

1. **Hazards Must be Evaluated Based on an Understanding of Coastal Physical Processes from a Geologic Point of View.** The coastal entire environment including the dunes, beach, and offshore areas are all part of one large geobiological system impacted by several different types of processes such as wind, waves, currents and storm surge.

2. **Recognition of Hazard Areas is Imperative.** By recognizing hazard areas, development can be directed away from areas most vulnerable to damaging coastal processes.

3. **Approaches to Property Damage Mitigation Must be Taken in Recognition of the Fact That Sea Level is Rising.** The present interglacial period is resulting in a worldwide shoreline migration as sea level rises over a sloping land surface. The sea-level rise is likely to continue in the foreseeable future and may accelerate over the next 50 to 100 years due to the greenhouse effect. As sea level rises, the impacts of storms will move in a landward direction.

4. **Alterations of Island Environments Due to Development Should be Repaired and Restored to their Natural, Predevelopment Setting**. This is especially true where the natural protective qualities of an island or community have been reduced. In many cases, this entails little more than restoring relatively small areas to their predevelopment state by rebuilding dunes or replacing native vegetation.

5. **Sand Volume and Vegetation Should be Augmented or at Least Maintained.** Emplacing new sand from an off-island source is better than moving sand from place to place on an island. The same is true for native vegetation.

6. **Potential for Property Damage must be Recognized as Both Site Specific and Regional in Character.** Each area presents a unique set of circumstances that requires unique solutions, although general principles can be drawn along the entire coastline.

7. **The Entire Coastal Zone Must be Considered When Applying Mitigation Plans**. Property damage mitigation can no longer be considered appropriate only for the first one or two rows of houses. Likewise, the coastal zone will continue to move landward as sea level rises. The storm-to-storm crisis approach should be replaced with a search for long-term solutions to this long-term problem.

Lessons Learned and the Ten Rules of Coastal Hazard Mitigation

Every hurricane, tropical storm and extratropical storm that affects North Carolina presents an opportunity to observe and learn more about the interactions between the natural and built environments.

Post-storm observations of the impact of Hurricanes Gilbert (1988), Hugo (1989), Bob (1991), Andrew (1991), Emily (1993), Bertha (1996), Fran (1996), Dennis (1999) and Floyd (1999) and many winter storms on developed shorelines helped define several principles or lessons learned regarding property damage mitigation. These generalized conclusions, which form the basis of the hazard mitigation alternatives and strategies contained in this report, are:

1. **Wide Beaches Protect Property**. The more beach available to absorb and dissipate storm-wave energy, the greater the possibility for mitigating damage to structures. The greater the distance between the zone of wave action and fixed construction, the better. When beaches narrow, replenishment or soft stabilization is a means of widening them and increasing their “storm buffer” capacity. Beach replenishment is, however, expensive and temporary. As erosion threatens, a better alternative may be relocation.

2. **Dunes Protect Property**. Sand dunes are often referred to as the “barrier” in barrier island, or as “nature’s shock absorber.” The mass of dune sand may absorb and dissipate storm-wave energy, thus protecting buildings located behind dunes. Where dunes, rather than buildings, are available to absorb the impact of waves and storm surge, post-storm beaches are markedly wider. Dunes are the sediment reservoir, banked for a stormy day, that provide sand to the beach profile as it readjusts to storm-wave energy.

   Dune systems reduce overwash potential. In addition, interior dunes provide elevation for building sites, reducing flood damage potential. Building placement can take advantage of larger dunes to afford wind protection. Dune width is as important as dune height.

   Ideally, no dune on any portion of a barrier island should ever be removed. Removal of interior dunes may lead to property loss and damage that could have been prevented if these dunes had remained intact. Killing or removing dune vegetation leads to reactivation of dunes by wind, creating blowouts and blowing sand that will be a nuisance, if not a hazard. Sand resources must be conserved, or even possibly added to island interiors, and vegetated to stabilize and trap moving sand.

3. **Vegetation Protects Property**. Overwash penetration and storm surge damage is noticeably greater where maritime forest is removed for development. This protective effect was well illustrated in South Carolina during Hurricane Hugo where neighboring structures suffered vastly different levels of damage depending on the degree of vegetative cover. Similar effects were noted on the coast of the Yucatan Peninsula of Mexico after Hurricane Gilbert in 1988. As much forest as possible should always be retained and, where appropriate, reforestation of areas where trees have been removed should be carried out. In addition to protecting and restoring

maritime forests, shrub growth should be encouraged in island interiors and marsh grass along an island's backside.

4. **Shore-perpendicular Roads Act as Overwash and Storm-Surge Ebb Conduits**. Elevating and curving roads so they approach the beach at an oblique angle will reduce the extent and amount of overwash. Obliquely angled and elevated roads also provide a more torturous return path for storm-surge ebb flow, thereby reducing scour potential.

5. **Dune Notches Create Overwash Passes**. Notches cut in dunes for beach access, views or construction sites are naturally exploited by waves and storm surge and by storm-surge ebb flows. Such notching can be avoided by constructing walkovers, elevating structures and taking particular care during construction. Where present, notches should be plugged or equipped with storm barriers that can be used to close these conduits prior to storms.

6. **Overwash and Storm-Surge Ebb is Intensified when Funneled by Structures**. As storm surge waters overwash an island and then return to the ocean, driven either by gravity alone or in combination with onshore/offshore winds, existing structures may constrict the flow and reduce the cross-sectional area through which the water must pass. This leads to increased flow velocities and scour, as demonstrated during Hugo, Gilbert and Floyd. Impermeable roads, drives, parking lots and similar hard surfaces in constricted spaces between buildings prevent infiltration and add to the storm-surge ebb current effect.

7. **Setbacks Protect Property**. Choosing a beachfront building site well back from the ocean is the easiest and least costly method of property damage mitigation. Setbacks work over the short term because the beach storm buffer remains wide and wave energy from major storms is typically reduced by friction on land between the beach and normal shoreline. If a shoreline is retreating, setback requirements are a short- to intermediate-term solution to property damage mitigation.

8. **Elevation Protects**. Elevation, whether achieved by natural land elevation, infilling of a construction site or by building on pilings may be the single most important site-specific factor in property damage mitigation. Structural elevations contained in local and state building codes are minimum requirements and property owners should consider them as such.

9. **Proper Community Governance Offers a Degree of Self-Protection**. Development where building codes are enforced and barrier island environments and processes are allowed to operate is less susceptible to property damage than development in areas where these issues are ignored or overlooked.

10. **Property Damage Mitigation is Best Accomplished at the Community or Island Level**. The foregoing principles are inadequate if applied singly or in a piecemeal fashion. Traditional mitigation techniques that focused on the shoreline have not reduced damage to interior island property or, in some cases, shoreline property. Although recommended actions may be site-specific, the total set of mitigation actions must be compatible and applied over an entire community or island.

Some specific lessons that have been learned over the years include:

- Damage to water, sewage, electrical, telephone and cable utilities may be avoided by proper installation.
- Appendages to houses, such as porches or decks, whose support columns tend not to be deeply embedded, are particularly vulnerable to storm processes.
- Although the National Hurricane Center estimated that Fran's winds may have reached 115 mph, most coastal structures were probably subjected to lower wind speeds.
- Breakaway walls on houses were inhibited by, and often caused damage to, the house's cross-bracing.

- Utilities, such as air conditioners, installed on or next to breakaway panels inhibited clean breakaways and caused damage to the utility.
- Mobile homes, manufactured homes and recreational vehicles are particularly vulnerable to storm processes

Hazards, Economics and Politics

Nature is not the only arena of the coastal zone, and hazardous processes are not the only performers. Property owners, planners and public officials can all mitigate the impact of hazards, but their theater is one of politics and economics. There is a great diversity of attitudes and responses to hazards among North Carolina coastal communities. Enough similarity among communities exists, however, to allow the following generalizations:

1. **Development Sites are Chosen on the Basis of Market Forces, not Nature's Forces**. Most coastal communities originally came into existence as port facilities, fishing villages, church camps, hunting clubs and resorts without hazard planning. Ironically, these communities are now located in some of the most hazardous locations in the world. Barrier island communities that were platted in traditional grids over fragile, dynamic environments are the most hazardous of them all.

2. **In Older Development, Residents Learned from Experience and Low-Risk Sites Tended to be Developed First, Leaving High-Risk Sites to Accommodate Growth**. This "modern" development, when threatened, often opts for engineering or "hardened" solutions rather than "softer" non-structural approaches to hazard mitigation

3. **Politicians, and/or the Political Pressures to Which they React, are Oriented Toward Giving Priority to Economic Development/ Management, not to Public Safety**. Development is seen as progress and as a way to increase the tax base. As in the pioneer days, such progress is still considered our manifest destiny.

4. **"Protective" Regulations to Reduce natural hazards are Often Viewed as Threatening to Developers as well as Some Property Owners**. Developers often resist regulations designed to protect property owners or builder occupants.

5. **Politicians are Member of the Economic Community**. Local decision-makers are often owners of undeveloped acreage, developers, suppliers of materials, lawyers, businesspeople and professionals who benefit, both personally and financially, from growth and development. Even if no conflict of interest is intended, some have a stake in development to protect. The approval of a new development, for example, may be influenced by the property available from a board member or by the vision of lumber sales or restaurant patrons, rather than an evaluation of the development's hazards and vulnerability.

6. **Politicians are the Employers, While the Day-to-Day Work is Carried Out by the Employees: the Hired Town Manager, Planner and Community Development Personnel**. These employees, by and large, do an excellent job for coastal communities. They are knowledgeable, realistic, committed public servants, but they answer to the elected politicians, not the general public.

7. **Collective Community Attitudes are Widely Variable**. Coastal communities that are suburbs or part of larger urban complexes have a high number of permanent residents who's perceived planning needs differ from communities with more transient populations and fewer permanent residents, where much of the property is "recreational." New residents in the latter types of communities are often inexperienced when it comes to the dynamic coastal environment and are therefore more likely to locate development in higher risk locations. Further, they also tend to lack the political power to influence planning and other development decisions.

8. **Developers are in Business to make Money, Not to Protect the Public**. The emphasis is on build-and-sell, not analysis of site-specific risk or island-wide mitigation or future relocation. In addition, the construction industry

prospers in the post-storm rush to rebuild.

9. **Catastrophes Often Set the Stage for Bigger Catastrophes**. Post-catastrophe “recovery” is a time of shock and haste to “put things right again” rather than a time of careful relocation and risk reduction. Houses, hotels and condominiums are often rebuilt “bigger and better” in the same high-risk locations. Big catastrophes, however, often bring new and/or stronger regulations, higher insurance rates, upgraded building codes, prohibitions or restrictions on future development and mitigation against recurrence of the hazard.

CHAPTER 1: THE NORTH CAROLINA COAST

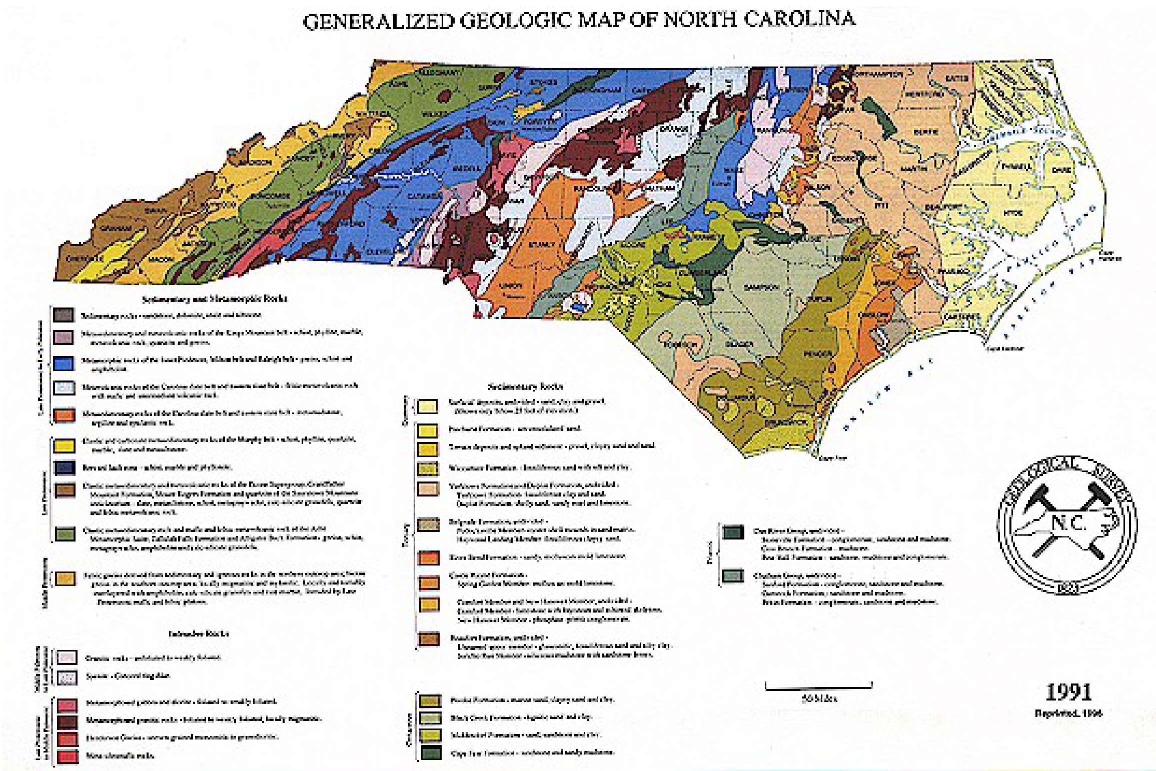
The Geologic Framework of the North Carolina Coast

In general, the geological history of the North Carolina coastal plain represents an era of several transgressions and regressions of the sea. These have resulted, through erosion and deposition, in the formation of several terraces. The most recent terraces, known as the Pamlico formation, forms a low, nearly level plain at an elevation less than 25 feet above present sea level.

The materials in this formation are fine sandy loams, clays, sands and some gravels. Deposits of recent age overlie the Pamlico formation. These include tidal marsh, beach sands and dunes. In marsh areas, the soil consists largely of accumulations of peaty matter. The thickness of the deposits varies from 15 to 25 feet.

The underlying geologic framework of North Carolina's barrier islands consists of sediment and rock units that range in age from just formed to 90 million years old, and the character of the state's coastal systems show dramatic differences that reflect the direct influence of the state's geologic heritage.
A line drawn from Raleigh through Kinston and Cape Lookout separates North Carolina's coastal system into northern and southern provinces. Each province has a unique geologic framework that results in distinctive types of barrier islands, inlets and estuaries with particular wave and tidal energies and processes.

FIGURE 1



Southern Province

The older geologic units that dominate the southern coastal province from Cape Lookout to the South Carolina border include rock formations from the Upper Cretaceous (90 million years ago) through the Pliocene (1.6 million years ago) periods. In this region only a thin and highly variable layer of Quartenary age surficial sand and muds were deposited during the past 1.6 million years. The older units are generally composed of harder rocks such as mudstones, sandstones and limestones.

These older rock units are associated with a large geologic structure called the Carolina Platform that underlies the region between Myrtle Beach, SC and Cape Fear, NC. During the geologic past, this platform rose slightly, and the rocks dipped toward the north and east, causing them to be eroded and truncated by the shorelines. As erosion cut deeper along the more uplifted southern coast, the older rock units were exposed.

Northern Province

In contrast to the southern province, younger geologic units - including Pliocene and Quaternary sediment formations less than 2 million years old - dominate the northern province from Cape Lookout to the Virginia border. In the northern province, sediments generally consist of unconsolidated muds, muddy sands, sands and peat sediments that thicken northward to fill the slightly subsiding Albemarle Embayment with up to 230 feet of sediment. Consequently, a gentle depositional topography is common along the present northern coastal system , with older rock units buried deep beneath the surface. These two very different geologic frameworks produce two different land slopes in the North Carolina coastal zone. The southern province is characterized by an average slope of 3 feet per mile while the northern province has an average slope of only 0.2 feet per mile. This difference in slope causes the ocean surface to intersect each province in two distinctly different ways, and caused rising sea levels to form two kinds of barrier island-inlet systems. The steeper slopes of the southern province have produced short, stubby barrier islands and narrow back-barrier estuaries. The gentle slopes of the northern province have produced long barriers with an extensive system of drowned-river estuaries.

North Carolina Barrier Islands

Barrier islands are, by definition, elongated bodies of unconsolidated sand that form offshore islands, separating the open ocean from the mainland. The following are the components of a barrier island:

1. **The island.** A typical barrier island is a maximum of 30 feet thick and its above water portion is made up entirely of sand from the beach (either by wind action or storm overwash). A number of sub-environments can be identified on each island, such as dunes, marshes, overwash fans, and berms.

2. **Inlets.** These are the channels separating adjacent islands, through which tidal waters from the ocean are exchanged with river waters from the continents. On natural islands, inlets frequently open and close (on a decades or millennia time scale). New inlets form during big storms as storm surge water returns rapidly to sea. In other words, inlets are cut through islands by the return flow of water from the sound to the sea. Because the volume of tidal and river water that must flow through an inlet is more or less constant over time, when one inlet forms another inlet usually closes. Some inlets migrate (e.g., Mason Inlet) while others remain in place (e.g., Bogue Inlet).

3. **Tidal Deltas.** Huge bodies of sand are associated with barrier island inlets. Tidal deltas are formed by sand that was fed into the inlet by the longshore currents from the ocean side of each island. The seaward body of sand is called the ebb tidal delta. Its size depends partially on the tidal amplitude. The greater the range between high and low tide, the stronger the currents and the larger the tidal delta. North Carolina ebb tidal deltas extend seaward distances ranging from l00 yards to one mile. The body of sand pushed into the sound by tidal currents is called the flood tidal delta.

4. **Shoreface (the lower beach).** In front of each barrier island is a steeply dipping, concave surface that is the innermost part of the continental shelf. This surface typically extends to 30 or 40 feet water depth, at which point the sea floor becomes much more gently sloping. This is the shoreface - an integral part of any barrier island that can be considered an integral part of the beach. Fair-weather waves push sand landward across the shoreface, providing the sand that eventually will become dunes. During storms, large quantities of sand move in the opposite direction (seaward) across this surface. If the storm is big enough, sand can move well beyond the shoreface and out to the continental shelf. This sand is permanently lost from the beach and island.

5. **The Beach.** The beach, which is actually the upper shoreface, is like a giant sand pump. Every grain of

sand on the "above-water" portions of a barrier island once came across the open ocean beach. Sand comes across either by storm overwash or by the action of wind. In the case of wind blown sand, the sand may go back and forth to the sea depending on the direction of the wind. When the beaches are wide and expansive, more sand blows into the islands than when the beaches are narrow.

How Barrier Islands Began

Barrier islands are a product of a rising sea level. Thus, they have been a particularly prevalent landform during the ice ages as the sea level has repeatedly transgressed and regressed across the world's coastal plains. The narrow, subtle sand ridges (sometimes labeled scarps or terraces on geologic maps) that abound on the lower coastal plains of North Carolina are former barrier islands that were stranded when the sea level receded during some past glacial retreat. Many coastal communities such as Harkers Island, Beaufort, and Morehead City, NC, occupy these former islands, taking advantage of the safety afforded by their elevation.

To illustrate the mechanics of barrier island formation, we need to consider the major sea level rise that resulted from the most recent retreat of the glaciers. As sea level began to rise, perhaps 18,000 years ago, it first flooded the former river valleys (See Figure 2). This formed the estuaries and simultaneously caused the formerly straight and uncomplicated shoreline to become highly irregular.

The intervening ridges between the former river valleys then became headlands projecting out into the ocean, which are particularly vulnerable to wave attack. As the waves chewed into the headland, longshore currents (see the picture below) distributed the eroded sands either upcoast or downcoast, forming spits that extended across the mouths of the estuaries. Wind, meanwhile, was piling up large sand dunes, forming shore parallel ridges.

Two events eventually caused the sand ridge-covered spits to become islands. First, storms eventually breached the spits cutting them off from their former longshore sand supply. Currituck Peninsula provides an excellent illustration of this process. During the last few centuries 26 different inlets lasting long enough to be named on a map have cut across this spit that extends south out of Virginia. At the same time the gradual sea level rise (responding to melting ice in the high latitudes) flooded the lowlands behind the sand dune ridges, eventually isolating them as islands. This is happening today behind the Currituck Peninsula near the Virginia-North Carolina border.
Once the sand spits became an island, a whole new set of evolutionary processes took over. The main sediment supply no longer was the adjacent eroding headlands. Instead, sand pushed ashore by waves from the shoreface became the main source of sand. Rivers no longer supplied sand to the shoreline since their mouths were miles inland at the heads of estuaries, a situation which still prevails today. As sea level pushed relentlessly upward, the newly formed islands adjusted to their new source of sand and began to migrate in a landward direction.

The Role of the Shoreface in Barrier Island Evolution

The coast of North Carolina is considered a sand-poor coast, which means that sand supply is low. This is because most of the sand that comes down the rivers is trapped

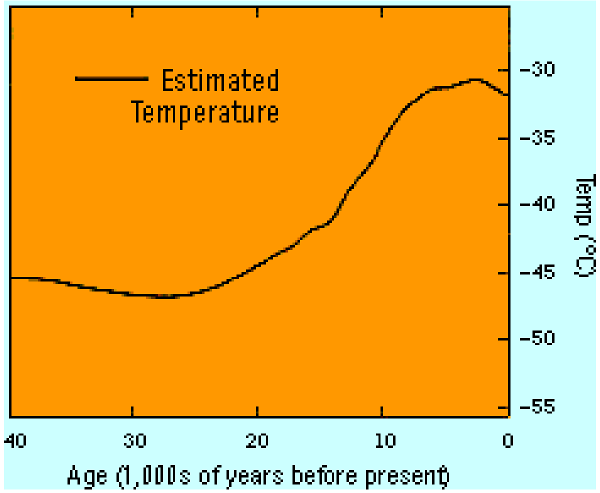


Figure 2: Estimated Temperature Change During the Past 40, 000 Years.

in the upper limits of the estuaries and does not make it down to the beaches. As a result, North Carolina has thin barrier islands that are “perched” on top of older geologic units.

Perched barriers rarely develop a profile of equilibrium because they consist of a thin layer of modern beach sediment sitting on top of a shoreface composed of older, eroding geologic units. Therefore, North Carolina barriers are actually thin accumulations of sand perched on remnants of preexisting sediment and rock units of variable ages, origins and compositions. The complexity of this underlying geologic framework, together with the physical dynamics of an individual barrier island, ultimately determines that island’s three-dimensional shoreface shape, beach sediment composition and shoreline erosion rate.

Today’s large-scale coastal topography is largely controlled by the riverine drainage system that was exposed on the continental shelf more than 10,000 years ago. As sea level rose, river valleys became inundated and filled with mud and sand. Coastal reaches dominated by former river valleys form the non-headland segments of the coast. These coastal segments are often characterized by rapid rates of shoreline recession. The non-headland segments are separated by inter-river divides (former ridges) composed of older and harder geologic units that form the headland

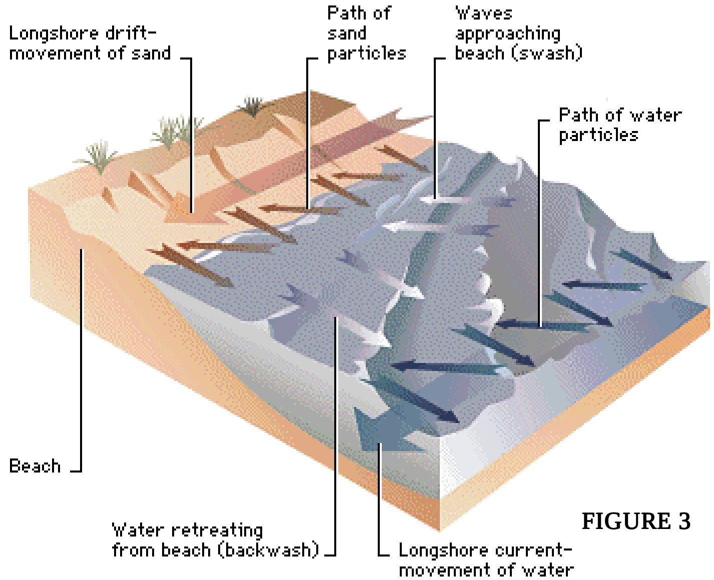


FIGURE 3

segments of the coast. These coastal segments are often characterized by seaward protrusions (capes) along barrier islands. The shoreface plays a major role in determining barrier island behavior. The North Carolina shoreface is a relatively steep surface extending from the shoreline to the innermost continental shelf to a depth of 30 to 40 feet. Among other things, the rate of shoreline retreat, the way an island responds and recovers from a storm, the size of the dunes and the size of the island itself are all greatly affected by the nature of the shoreface.

Sections of beach between Nags Head and Virginia, for example, contain high concentrations of nonshell gravel that is usually only found in locations where gravel-bearing pre-historic river channels underlie the barrier. Topsail Island, where shells of an extinct fossil oyster and associated limestone gravels occur in great abundance, is another example. These gravels are derived from the erosion of Oligocene hardbottom scarps that crop out on the inner continental shelf and are subsequently transported to the beach during storms.

Headland-Dominated Shorefaces

Headland-dominated shorefaces occur on the high inter-river features or ridges composed of harder sediments and rocks of older geologic units. These rocks sometimes may crop out on the beach, as do the Quarternary coquina rocks found on the beach between Kure Beach and Fort Fisher. It is more common, however, for these rock outcrops to be on the underwater shoreface. An example of a submarine headland is found on northern Topsail Island where Oligocene limestones from high relief hardbottoms immediately in front of the beach, and extend beneath the barrier island. These formations affect the island’s shape and erosion rate, and can have an impact on incoming waves.

Nonheadland-Dominated Shorefaces

Nonheadland-dominated shorefaces are common along the North Carolina coast. The material that crops out on these shorefaces and affects barrier island behavior is generally composed of four kinds of sediment:

Valley-Fill Shorefaces

Some barrier islands overlie prehistoric river valleys that were filled as the sea level rose to its present height. Beneath these barriers lie thick accumulations of soft river and estuary channel-fill sediments. Barrier islands migrate faster across such soft valley-fill complexes and create indentations in the coastline because these sediments exhibit higher erosion rates that the surrounding sediments. Examples can be found in the Outer Banks where the former Roanoke River valley passes beneath the barrier in the shoreline reach between Kitty Hawk and kill Devil Hills, and where the former Neuse and Tar River valleys lie beneath Ocracoke Island.

Inlet-Fill Shorefaces

Barrier island segments underlain by the fill of either historic or prehistoric barrier island inlets have a shoreface composed of the unconsolidated sand and gravel that back-filled the inlets as they migrated.

Migrating/Retreating Shorefaces

In areas where narrow and low barrier islands are actively migrating up and over the back-barrier estuary, the shoreface is composed of peat and mud sediments. These relatively young sediment units extend from the estuaries, under the barrier island and crop out within the surf zone and shoreface. Tree stumps and peat blocks, commonly seen during the winter months and after storms, are telltale indicators of this type of erosive shoreface.

Seaward-Building Shorefaces

In a few places where there is an adequate sediment supply, the shoreface temporarily builds, or progrades, seaward with sand similar to the composition of the barrier island. These shoreline segments occur only immediately adjacent of the capes and inlets and are often short-lived phenomena. Two examples are the eastern tip of Shackelford Banks and Sunset Beach.

A barrier island's shoreface type is a good predictor of future island changes. When an island does change, in response to a hurricane for example, appropriate mitigation alternatives should be based, in part, upon the island's specific shoreface type.

Beach Dynamics

The beach is one of the earth's most dynamic environments. Defined as the zone of active sand movement, and extending from the toe of the frontal or primary dune to an offshore depth of 30 to 40 feet, the beach is always changing.

Interest in coastal processes has evolved from a purely scientific endeavor into one of great applied societal importance. An understanding of basic coastal processes is fundamental to the development of an effective coastal hazard mitigation plan.

Sand/Sediment

Sand comes in all different sizes, shapes and compositions. The dominant mineral of North Carolina beach sand is quartz, the same mineral that glass is made from. Seashells that have been ground up by the waves and other sand grains (which act as an abrasive) are also important and range from sand size (1/16 to 2 millimeters) to their original shell size (a couple inches wide).

Grain size of the sand is important because it makes a difference in the rate of shoreline erosion. Under the same wave conditions, a beach covered with fine sand is more likely to move around than a beach covered with gravel or boulders. This is simply because it's easier to move the small light stuff than the big heavy stuff. Grain size also determines the slope of the beach. Beaches with finer grain sizes tend to be flatter (between the high and low tide line) with gentler slopes than beaches with larger grains.

Sand is constantly moving to and from the beach. This movement (often called the littoral drift or longshore transport) occurs alongshore, or parallel to shore, and on and offshore, perpendicular to shore. Sand moves due to the joint action of waves and currents. Breaking waves kick up sand from the seafloor and the currents move it. If that quantity of moving sand changes, the beach will either retreat (erode) or build out (accrete). If the quantity increases, the beach builds out. If the quantity decreases, the beach will retreat towards land. Very often, the cause of change in sand quantity is due to humans. For example, when we build jetties such as those at Masonboro Inlet on Wrightsville Beach, we trap the sand that was moving alongshore to some other beach. This starves the beach on the other side of the jetty and the shoreline there erodes.

This is part of the reason why sand can come from a wide range of places. If there are bluffs or cliffs backing the beach, they can provide sediment when they are attacked and eroded by waves (during storms or fair-weather). Along the North Carolina coast there are no cliffs. Instead, dunes along our barrier islands supply most of the sand to the beach.

Rivers can also furnish a lot of sediment to beaches. In North Carolina, however, estuaries often trap sediment miles from the shoreline and prevent it from reaching island beaches. The shells on a beach supply sediment to the beach as they are broken up by the waves or by scavenging organisms such as skates or rays. Beaches also gain sand from the continental shelf. During fair-weather, waves slowly push ashore sand and shells from water depths as great as 30 or 40 feet. An increasingly important source of sand on North Carolina beaches is nourishment sand which is dumped by man.

Many communities now nourish their beaches, bringing in sand from inland quarries, local inlets or from the offshore shelf.

Waves and Wind

Waves are directly and indirectly responsible for almost all sand movement on beaches. Waves are caused by the friction of the wind on the surface of the sea. As the wind blows across the surface, energy is transferred from the air to the water. Some general rules of thumb are: 1) Higher winds equal higher waves; 2) The longer the wind blows, the bigger the waves; and 3) The greater the distance the wind blows (fetch), the bigger the waves.

Sometimes waves form currents that carry sand. The longshore current is the most important of these. Longshore currents form because waves approach the shoreline at an angle. The greater the angle between the waves and the shoreline (up to 30 degrees), the stronger the longshore current. The direction of these currents is not set in stone. There are reversals in the wave direction approaching any beach, and the longshore currents switch accordingly to the new (opposite) direction.

Most of North Carolina has longshore currents moving from the north to the south, or “down the coast.” Indicators of longshore transport at work in North

Carolina include inlets that migrate (e.g., South Topsail) and the build-up of sand on one side of a groin or jetty and erosion of sand on the other side of the structure (e.g., Masonboro Inlet).

Waves can also transport sand on the land. During storms, waves wash over the land carrying sand as overwash. This sand can be deposited way beyond the beach on the center - or even the back part of the island - depending on how big the waves are and how long they last.

Sand from the continental shelf is usually carried onshore during fair-weather and offshore during stormy weather. During fair-weather, sand is slowly moved ashore by the orbitals of waves that are “scraping” the bottom. During a storm, huge volumes of sand can be moved in just hours because waves are steeper, and strong seaward directed currents are formed.

Water is frequently pushed ashore by the wind in a storm, temporarily raising the level of the sea. This is called wind set-up. It is the seaward return of this raised water that carries sand in an offshore direction. So the energy of the wind and waves causes beach sand to move on, along and off a beach. While normal fair-weather conditions provide a daily movement of sand, they do so on a much smaller scale than the wind and wave conditions during a storm. Storms can provide instantaneous adjustments in the dynamic equilibrium of a beach.

The natural laws that govern beach dynamics dictate that they build up in good weather and retreat (usually only temporarily) during storms with big waves. Beach behavior is dependent upon four factors:

1. Wave energy
2. Quality and quantity of beach sand
3. Shape and location of the beach
4. Rate of sea level rise

In general, beaches maintain a natural balance referred to as a “dynamic equilibrium” of these four factors. When one factor changes, the others adjust accordingly in order to maintain balance. For example, beaches will react to human impacts in ways that restore the dynamic equilibrium, but that may damage or destroy buildings and infrastructure.

Barrier islands respond in predictable and sensible ways to all kinds of natural events such as storms, rising sea levels, retreating shorelines and the migration of inlets. In a technical sense, barrier islands exist in a dynamic equilibrium involving a number of factors including waves, tides, wind, sand supply, underling geology, vegetation and sea level change

Waves

Waves are critical in barrier island evolution because they are responsible for carrying sand to the beach from either the continental shelf or from adjacent islands. This process is so important that barrier islands do not exist on shorelines of very low wave energy (e.g., the Florida shoreline bordering the northeast corner of the Gulf of Mexico). Storm waves wash over the island and bring huge volumes of sand into the interior of the island.

This build-up of island elevation is a critical part of island evolution during a rising sea level. The overwash phenomenon was amply demonstrated on many East Coast barrier islands during the 1991 Halloween storm. In the village of Rodanthe, NC, overwash fan thickness from the storm exceeded five feet in places.

Barrier islands also do not exist where tidal amplitudes are in excess of 4 meters. Why this is the case is not entirely clear. According to studies made by Miles Hayes, tides control the spacing of inlets, which is another way of saying that tides control the length of islands. With large tidal amplitudes, where a lot of water must flow in and out of inlets, inlets are closely spaced and islands are short. The Georgia islands, where normal tides are 7 feet, are good examples of short islands. With small tidal amplitudes, where less water must flow in and out of the sounds, the inlets are widely spaced and the islands are long. The NC Outer Banks has long islands and a tidal range of less than three feet.

Wind

Over time, wind is capable of carrying large volumes of sand from the beach into the dunes. Prevailing directions of wind are important in determining the overall island sand volume that is available to wind move off the beach and into the island. The importance of wind is demonstrated by the difference in width and sand volume of two adjacent islands in the Cape Lookout National Seashore: Shackleford Bank and Core Banks.

The dominant winds in this area are from north (winter) and the south (summer). Shackleford Bank, a wide, high sand rich island is oriented east-west and for significant periods of time each year, sand is blown into the vegetated dunes. Core Bank, a narrow low-lying island with few dunes is oriented north-south. On most days of the year sand blows up or down the island, rather than across. As a consequence, little sand is blown from the beach to the island interior and few dunes form.

The sand supply of an island is another major factor determining island width and volume: the bigger the supply the greater the width and volume. Occasionally, as in some Texas islands and those on the Mississippi Delta, sand supply is directly traceable to river sources. Mostly however, American barrier islands receive their primary sand supply from the adjacent continental shelf. Why this sand supply varies both aerially and temporally along barrier island chains is not well understood. In some cases, sand supply probably will be controlled by the nature of the materials that the island is migrating over.

The geologic framework or underlying geology of barrier islands controls the location of some islands and also affects the size and composition of the sand supply. On the Outer Banks of North Carolina, stretches of gravel beaches almost always correspond to the offshore location of old deposits of river gravel laid down when the sea level was much lower. Fossil shells and fossil shark teeth are common constituents of some barrier island sand (e.g., Topsail Island), all derived from underlying strata. Even the erosion or migration rates of islands are partly controlled by the underlying geology. Islands underlain by mud are prone to more rapid retreat than are islands underlain by sand.

Vegetation

Vegetation plays a major role in barrier island evolution as well. For example, onshore winds blow a lot of sand into the islands. However, when the winds reverse and blow offshore, not nearly as much sand is carried towards the sea. This is because dune vegetation holds the sand in place once it gets onto the island.

Dune Vegetation

The manner in which dune vegetation spreads seeds and rhizomes is a major control of island topography. Sea Oats, the dominant southern US dune plant, tends to form in clusters and as a result natural dune lines on southern islands have gaps. The gaps are used by storm overwash to bring sand onto the island and build up its elevation. In contrast, dunes dominated by American beach grass will have fewer gaps. This prevents storm overwash except in the larger storms. Penetration of the storm waves through the dunes is important because it brings sand to the island, raising its elevation. This is an important way for the island to compete with a rising sea level.

Sea Oats are easily distinguished by their long, thin, protruding stalks with grains of attached “oats.” These “oats” are flat, yellowish oat-like spikelets which grow in the summer and fall (from June to November). The stems are cylindrical and the linear-shaped leaves grow on both the base of the plant as well as along the stem.

From Cape Hatteras northward, dune grass is composed predominantly of American beach grass (Ammophila breviligulata). This, too, grows well after being buried by sand. But in contrast to the Sea Oats, American beach grass grows well laterally, and between storms it will even spread out to the edge of the normal high water line. American beach grass is increasingly planted in the dunes by oceanfront property owners well south of Cape Hatteras because it grows rapidly and transplants easily. American beach grass is best distinguished as the near beach dune grass without stalks. It also remains partially green during the winter.

Maritime Forests

The forests found on the back side of barrier islands are called maritime forests. They have a smaller number of plant species than mainland forests due to consistent high winds and the salt spray from the beach. On most North Carolina barrier islands, cedars and Live Oak are the principal floral components of the forest. The diversity of vegetation on North Carolina barrier islands depends on their size and elevation, which in turn controls the extent of exposure for plants to wind and salt.

On Bogue Banks, which is wide and has high dune ridges, there are over 500 different species of plants. On Core Banks, which is low, narrow, and frequently washed over by storms, the number of naturally-occurring plant species drops to 25. In between these two is Shackleford Banks, which has almost 300 species. Shackleford has high dunes, but it is not as wide as Bogue Banks. These three adjacent islands illustrate how forest species diversity adapts to the specific nature of the barrier island.

Salt Marsh

The third major vegetative component of barrier islands is the salt marshes found along the sound shoreline. This shoreline is much quieter than the ocean beach, with the only significant wave action generated by offshore winds or storms. The dominant marsh grass in North Carolina is Spartina which is adapted to the repetitive wet and dry cycle of the tides. The thick congregation of marsh grasses baffles what wave energy does strike the sound shoreline, which then traps the sediment from the water much like dune grasses trap it from the air. The marshes then build up mud and peat as the grasses grow, trap sediments, die and are buried.

Sand supplied by overwash fans also builds up the elevation of the marshes, allowing them to survive during a rising sea level. The function of sea level change is discussed below due to its special role in island migration. As already mentioned, barrier islands are a product of a rising sea level. No sea level rise means no valleys are flooded to form estuaries, and no islands are built across the mouths of estuaries.

Beach Features

Who do the beaches belong to? Are all the beaches owned by private owners? No. Can you access the beach from someone's property? Probably not. Some, such as Cape Hatteras National Seashore, are state or federally-owned. In North Carolina, the beach itself is public property, but gaining access to it is often restricted by private property. If you are lucky enough to enjoy a stroll on one of our magnificent North Carolina beaches, keep an eye out for the following features, each a clue to the story of the beach.

Beach Shape

The shape of a beach is oftentimes called a beach profile. The profile extends from the dune, across the beach, and offshore under the waves. The beach shape or profile is controlled by all three of the factors in the dynamic equilibrium of the beach. The beach automatically responds to any change in sea level, the amount of sand available and the characteristics of the wind and waves. Grain size can also control the slope of the beach.

The most spectacular changes in beach shape, changes that can happen very quickly, occur in storms. When storms occur, sand is often moved from the upper beach to the lower beach or offshore. This flattens the beach. Have you ever visited a beach after a storm and noticed that the beach is wide? Beaches flatten in a storm to spread the energy out over a broader zone and take on a dissipative beach profile (also called a “winter” beach shape). This is a defense mechanism by the beach to prevent losing even more sand. Between storms and in quiet weather, this sand moves ashore and the beaches tend to steepen and get narrower. Have you been to the beach in the summer and noticed that the beach is steeper? This is commonly referred to as a reflective beach profile.

Sometimes the underlying geology controls beach shape or profile. If the barrier island has rocks, peat or mud underneath it (instead of being a huge pile of loose sand), these harder sediments may stick out on the beach profile.

Have you ever noticed some rock-like materials at Kure Beach? These are rocks made out of old shells that were deposited and buried thousands of years ago. They now crop out on the beach and dunes in this area and control where the beach is and what its shape is. Farther north at Topsail Island and in places along the Outer Banks, peat outcrops are visible on the beach. This shows how fast the island is migrating because those peat deposits are the buried remnants of freshwater marshes that used to be on the backside of the island!

Our beaches exist in a state of dynamic equilibrium with the various forces acting on them each minute of every hour of every day. Man, in an effort to preserve the natural beauty of the beach, has often become another force acting on the beach. The beaches respond to man’s impacts as well. What if someone builds a wall or structure that disrupts the dynamic equilibrium? Mother Nature will react just like to any other change, but oftentimes the reaction is not what man wanted or intended. The features you see on the beach, both natural and artificial, are direct representations of the dynamic forces at any given beach. Each feature, whether it be a sandbar, berm, dune, beach cusp or ripple mark, tells a story about what is going on at that beach. If we know how to listen, we can read the beach for its clues.

Offshore Bars

Sandbars are underwater mounds of sand that form close to the beach anywhere from 100 to 300 meters offshore. Some beaches have more than one sandbar, with the bar closer to the beach called the inner bar and the farther one called the outer bar.

From the beach you can tell where these underwater features are by where the waves are breaking. Sandbars are a sudden shallowing of the seafloor that trip up waves before they would without a bar. If the bar is far enough offshore, the waves that break on the bar might reform and break a second time on the beach. Sandbars come in many different shapes and sizes. Some are crescent shaped while others are long and straight.

Wide and low bars may contain a huge volume of sand, while smaller and narrower ones may not contain as much sediment. Bars can extend for miles down a beach, with gaps in between the individual mounds of sand. Over time these bars move around in response to waves and currents much like the beaches do. Storms can create sandbars where previously there were none, with all the sand they move offshore being dumped in one place. After the storm has passed, fair-weather waves will slowly move that sand from the bar back to the beach. If there are two sandbars offshore of a beach, and both are moving about with the changing waves, the two bars can merge into one. Scientists at Duck, North Carolina, are using time lapse video cameras to watch the sandbars found there. They use the position and shape of the breaking waves to tell them where the bars (usually two) are, what shape they are, and how they are moving over time.

Sometimes the bars march right up to the beach and become a part of it. When a sandbar is welding itself to the beach, the top part of it can become exposed at low tide. Have you ever been at the beach at low tide and been able to walk along the water's edge only to have a large puddle of water in a depression next to you? Some people call the high part you're walking on a ridge, with the low depression called a runnel. Oftentimes, these features will have ripple marks on the surface of the sand left behind by the moving water. Sandbars are an integral part of the dynamic beach, and if you know how to read the waves you might just spot one.

Berms

The berm is the flat part of the beach that you sunbathe on. There is a berm crest somewhere close to the water that is the highest part of the berm. The rest of the berm usually slopes slightly landward back to the toe of the dunes. Some beaches might have more than one berm, kind of like terraces. Berms probably form during storms that are long gone, and if there is more than one, then they each represent different storms. The back part of the berm is thought to be the farthest back that storm waves cut into a beach. So, each berm indicates a current or former equilibrium position of the beach. On nourished beaches like Wrightsville or Carolina Beaches, berms are artificially created when new sand is dumped on the beach. A lot of times, however, engineered berms are not in dynamic equilibrium with the waves and currents.

Scarps can be cut in an artificial berm as waves attempt to create a more natural berm. These scarps look like miniature cliffs on the beach, except they are right at the water's edge instead of at the back of the beach!

Beach Cusps

Beach cusps can sometimes be carved out of the berm of a beach. These horn-like features consist of protruding sections of the beach that alternate with small embayments. Beach cusps give the beach a wavy or undulating appearance. If you have ever walked along the water's edge only to find yourself going up and down a gently rolling surface, you've probably been walking across a series of beach cusps. These cusps are typically uniformly spaced (anywhere from centimeters to tens of meters apart) and look like arcuate scallops from above.

When you are on a beach with beach cusps, you will notice that the waves seem to wash up in the embayments only. The wave swash is deflected by the horns into these rounded-out areas. In this way the horns are usually gaining sand (accreting) and the embayments are losing it (eroding). The difference in elevation between the horns and embayments is usually on the order of a couple feet or more. Scientists are not exactly sure how beach cusps form, but they do know that they are ephemeral features that can change shape and size with any given wave conditions.

Swash Marks, Ripple Marks, and other Bedforms

The surface of the beach exhibits a diverse variety of patterns. These so-called bedforms and structures form as a result of the currents in the wave swash, moving the sand around until the grains settle down. Each type of bedform provides a clue to the currents and waves that created them. One can actually observe these features forming by standing in the uppermost swash zone of the beach.

One of the more prevalent bedforms is swash marks. These are small ridges of sand or debris that are left behind by the most landward reach of an individual wave swash. At low tide, the entire beach may be covered by these long wavy lines, each a reminder of the single wave that created it.
Ripple marks are another bedform found in the intertidal zone of the beach. These bedforms can form anywhere there are the right kinds of currents and sediments. These ridges of sand, larger than swash marks, line up in a repetitive pattern perpendicular to the direction of the water current or wind that created them. They look like miniature dunes and can cover very large areas. Ripple marks are formed in the sand by wind or water moving over the beach surface at a high enough velocity for the sand to be picked up and moved.

Another type of bedform is rill marks. Rill marks look like small streams crossing the beach. They form as water pours out of the beach when the groundwater table is intersected by the surface of the beach. They commonly form after storms when the beach surface has been moved back by erosion.

Groundwater on the Beach

Have you ever sat and watched the swash running up a beach, and noticed that sometimes the swash disappears into the sand instead of running back to meet the next wave coming in? This indicates that the water table is low on the beach, the sand in the swash zone is dry and sucks up the water brought in by the swash. When the swash does not sink into the sand like a sponge, but instead washes back to the sea, the water table is high on the beach. This means that the line where the water table intersects the surface of the beach is farther up the beach than where the swash is running back and forth.

So why is the position of the water table on the beach important? The water table is important because it influences how much sand will be picked up by the swash and waves. If the water table is low, all of the sediment that is being carried by the swash is deposited on the beach as the water infiltrates the sand. If the water table is high, more sediment can be picked up by the swash and waves since each sand grain is already surrounded by water.

Beach Erosion

Nipping away at the edges of the continent, ocean waves are slowly taking away land area. At the same time, the continents are enlarging by such processes as mountain building and the growth of river deltas. Today the forces of the sea are winning and the continents are shrinking since sea level is rising faster than the continents can provide new land.

A shrinking continent translates into trouble for people when buildings, highways and services are built next to the shoreline as they so often are in North Carolina. In the absence of buildings, land is lost when the shoreline moves back but the beach remains as a wide, healthy buffer of sand. No erosion problem and no beach problem exist as long as no buildings are built next to the shoreline.

Shoreline erosion has been with us for a long time. The Romans complained about it and built structures to hold the shoreline in place, usually near harbor mouths. The erosion problem is immensely greater now than it was in Roman times because the shorelines of the world are now jammed with buildings, in open defiance of the forces of nature.

The causes of shoreline erosion have been the topic of intense study for the last several decades. Although it's still difficult to sort out all the factors involved, we are getting closer to understanding the natural balance between processes and materials at the shore, as well as man's influence on that balance. In North Carolina we understand the problem probably as well as in any other state. Rising sea level is the dominant force behind long-term shoreline erosion. In the short-term, storms can cause tremendous amounts of local erosion.

Sea Level rise will likely accelerate in coming decades due to the Greenhouse Effect. This expected climate change may also increase the size and frequency of storms, although this is less certain. The 1997-1998 El Nino temporarily raised sea level by 1 to 3 feet off South America, and increased storminess and coastal erosion along our Pacific shores. La Nina, the opposite of El Nino, seems to increase storminess on the East Coast.

The volume of the natural sand supply is another major erosion factor. In North Carolina sand arrives on the beaches mostly from the continental shelf, pushed ashore by the action of fair-weather waves. Big storms tend to take the sand away and can carry it offshore, sometimes too far off to be recovered. After Hurricane Fran, there was very little beach recovery on Topsail Island, leaving many buildings in immediate danger from the next storm.

On most American shores, humans are likely the principal cause of erosion. For example, construction of dams has trapped the supply of river sand to the beaches. This problem is typical for California and parts of the Texas coast, but is not important along much of the East Coast and North Carolina where rivers dump their sand load in the upper estuaries, miles from the ocean shoreline.

People have caused further interruption of the shore's sand supply by dredging channels for boat access to inland waters and ports. Many, if not most, inlets in North Carolina are periodically deepened by dredging. When the deepened channel is protected by jetties, long walls built parallel to the shoreline, the cutoff of sand supply is almost total and erosion rates skyrocket. Jetty-caused erosion can extend down the coast for many miles.

Dunes

A dune is a pile of wind-blown sand. They come in a huge variety of sizes and shapes, depending on the amount of sand available, the size of the sand, and the prevailing wind directions. Over time they can grow, shrink, or move (migrate) in the direction of prevailing winds. They can be created and destroyed by either nature or man. Dunes can roll over trees and buildings or be washed away by the next storm.

The beach is the sole source of sand for coastal dunes, and every single grain in a sand dune has come across the beach at one point in time. The sand can come ashore from both the sound beach and the ocean side beach. Dune building is helped along by the onshore winds characteristic of coasts. Regardless of the general wind circulation patterns of the region, winds will blow onshore at least some of the time. These winds occur most commonly when the land is warmer than the sea, causing air to rise from the land, which in turn causes air from the sea to blow onshore to replace it. The winds can often reach great speeds that move large amounts of sand in short periods of time. You may even run across a glass bottle left on the beach that is "frosted." The sand grains were moving fast enough so that shine and clarity of the glass bottle are essentially sandblasted off.

Evidence of the beginnings of dune development could be right in front of your eyes if you're on a beach. Dunes commonly begin as piles of sand accumulated in the lee of beach debris such as piles of seaweed, clumps of salt marsh "straw" and a whole host of human garbage (fishing nets, bottles, etc.). Beach debris slows down wind velocities or blocks the wind, causing sand to accumulate. Eventually, seeds of dune grasses (especially Sea Oats) find their way to the new piles of sand, germinate, sprout and start to trap sand. As the plant grows it continues to cause more sand to gather. If all goes well and the surf zone is far enough away a new dune is born! As the dune grows the vegetation keeps moving up and out, holding much of the sand in place.

Dune Sand and Stratification

The sand that makes up the coastal dunes of North Carolina is usually finer than the sand grains on the beach. Wind cannot move the large particles that waves do. Consecutive layers of dune sand and other sand-sized sediment build on top of each other and, over time, the layers form a unique type of stratification called wind cross-bedding. Cross-beds, which can usually be seen in erosion scarps next to the beach, have several sets of sand layers that incline at different angles. Each set of layers indicates the former surface of the dune. In North Carolina, the dune stratification is usually seen as fine, sand-sized shell material or heavy minerals interspersed with regular quartz sand. The layers of shells are usually brown in color and the layers of heavy minerals are black.

You have to stand very close to an exposed dune surface to see the individual layers. The layers are very thin, often one to two grains in thickness. They probably form in a burst of wind, which brings in a new layer of quartz sand. Between bursts, lower velocity winds cause the lighter materials to be blown away, leaving behind heavier grains and thus forming a layer.

Dune Types

There are three types of dunes in North Carolina:1) vegetated, 2) artificially induced, and 3) medanos. Vegetated dunes can be seen on most of North Carolina's barriers and beaches. One exception is Masonboro Island, which is overwashed so frequently that dunes have no time to form. When present, the vegetation is usually American Beach grass or Sea Oats. The vegetation serves as an anchor for wind-blown sediment. When the grass is removed by storms, or even by overgrazing, the dunes are destabilized and can begin to migrate landward.

Artificially-induced dunes are often dunes built up by the planting of grasses or through the use of sand trapping fences. These are common along the shores of North Carolina as many property owners attempt to build up dunes in front of their homes. Another form of artificially induced dunes is the bulldozed dune. This practice becomes more widespread each year in North Carolina. These dunes are described in more detail later.

Medanos are the third type of dunes and derive their name from the Spanish word for "coastal sand hill." Medanos are a distinctive type of unvegetated dune. They are high, steep, isolated sand hills ranging in height anywhere from tens to several hundreds of feet. Medanos are formed by winds moving sand upward toward the summit from several directions. Despite their lack of vegetation, Medanos have very little overall migration because of the number of different wind directions that transport wind to the dunes. These dunes may simply represent places where there was an exceptionally high amount of sand available on the beach. Medanos can be found on the Outer Banks in Nags Head and Kill Devil Hills and include Jockey's Ridge, Run Hill Dune, and the Wright Brothers Memorial. The latter is now held in place by a mowed lawn! Wild grapes are found in patches on the top of Run Hill Dune. These grapes came from vines that were growing on the tops of the trees now buried by the dune.

The dunes of coastal North Carolina form a somewhat continuous ridge of sand facing the sea. The size of the dunes is mainly a function of sand supply -- the larger the supply from the beach, the higher the dunes. Most dunes have gaps between them where the storm waves penetrate into the islands. When the foredune is very large, like the 30 foot high dunes on Bogue Banks, there are no overwash gaps. Overwash deposits are easily distinguishable from dune sands because of their high shell content.

Why do some barrier islands and beaches of North Carolina have many dunes and some have only a few low ones? The answer is largely related to wind direction. Core Bank, oriented north-south, probably does not have dunes because most winds blow up and down the island (parallel to), not across it. In contrast, adjacent Shackleford Banks, with an east-west orientation, has very large dunes because most of the winds blow across it.

Blowouts

A blowout is a flat area or surface in a dune field that lies below the elevation of the adjacent dunes. These are formed by the wind removing sand (i.e., wind erosion). Blowouts are flat because the sand is blown away until the sand surface reaches the top of the water table. The wet sand resists being blown away and the surface becomes vegetated. You can test this by digging a hole with your hands on a North Carolina blowout. Less than a forearm length below the surface, you will reach freshwater. The best place in North Carolina to see blowouts is on the western half of Shackleford Banks.

Bulldozed Dunes

In North Carolina, it is legal to bulldoze beaches to form dunes or piles of sand up against buildings for storm protection. Almost every beach with buildings on it is bulldozed occasionally, usually after storms.

It is easy to spot bulldozed dunes because they contain a lot of shell material - a rare component of natural dune sand. After a few days on the upper beach, wind will blow away the finer sand on the surface, causing a layer of shells called a “shell lag” to form on the surface.

Natural dunes, especially those with roots entangled throughout the sand, provide a solid (if temporary) bulwark against a minor storm. When attacked by waves, they quickly form a scarp or small cliff. Subsequent waves are at least partly reflected from the scarp, rolling back down the beach and smashing into the next wave coming ashore. Bit by bit, however, the dune scarp moves landward under wave attack.

Helping to reinforce and strengthen natural dunes (in addition to the beneficial effect of plant roots) are electronic forces between the uniform sized sand grains and the water between the grains. These are called Vanderwaal forces. In bulldozed dunes, which are made up of beach sand with a wide size range of quartz grains and shell fragments, neither roots nor Vanderwaal forces work. As a consequence, the dunes erode with much greater ease. The bulldozed sand, minus the animals that once lived in them, returns the beach (usually during the next storm).

FIGURE 5: Beach Scraping in Ocean Isle Beach, NC prior to Hurricane Floyd

Bulldozing dunes is not a good thing for beaches. For one, it is a form of beach erosion. For another, it kills all the organisms in the beach -- the mole crabs, the coquina clams, and all the microscopic organisms that live between sand grains. For days after bulldozing, seagulls have an unexpected bonanza, swooping and grabbing the stranded and struggling critters of the beach that are now high and dry in the bulldozed dune. For a few days after bulldozing, the odor of rotting organisms can provide an unpleasant atmosphere for beach strollers.

North Carolina Estuaries

North Carolina’s estuaries are drowned lowlands that lie behind the barrier islands. In places where these lowlands are drowned river valleys, the ocean has flooded up the river’s channels to the point where the valley bottom rises above sea level. The resulting shore-perpendicular estuaries have two sources of water: rivers and inlets.

Estuaries of the Southern Province

The narrow, coast-parallel estuaries that back the barrier islands of the southern province range from open water to areas dominated by salt marshes and tidal creeks, depending on the width of the estuarine system. Estuarine systems tend to become narrower, and open-water bodies become smaller, toward the southern end of the province.

Because of their relatively small surface area, water in southern province estuaries experience minimal effects from waves and wind-driven tides. Consequently, the perimeters and interiors of these estuaries are dominated by sloped mudflats and extensive *Spartina* salt marshes riddled with tidal channels.

These narrow estuaries are regularly flooded, tidal-current-dominated coastal systems that have been highly modified by human activity, including an extensive network of dredged channels and associated spoil islands.

Estuaries of the Northern Province

The back-barrier sounds of the northern province are medium to large, coast-parallel estuaries. The presence of only four major inlets in more than 190 miles of barrier islands, plus a major input of fresh water from rivers draining the Piedmont and Coastal Plain, result in estuaries with low-amplitude, regular astronomical tides and highly variable salinities. Only in the regions around inlets, subject to direct oceanic influences, do waters exhibit regular astronomical tides and develop high-brackish salinities.

Because the sounds of the northern province have relatively large surface areas with moderately uniform depths and no interior salt marshes, they are highly influenced by wind waves and currents as water moves in response to irregular and rapidly changing weather events. Normal wind tides are minor (less than 1 foot) with storm tide amplitudes ranging from 3 feet up to 10 feet during hurricanes. In general, the back-barrier sounds of the northern province tend to be irregularly flooded, wind-tide-dominated coastal systems surrounded by scarped and rapidly eroding marsh and sediment bank shorelines.

Sediment Shorelines

About one third of North Carolina's estuarine shoreline is dominated by sediment banks consisting of sediment beds of Quaternary age or older. Sediment bank shorelines consist of a wave-cut platform and an associated wave-cut scarp that are eroding back into older sediments. The sand that forms the beach along the shoreline is derived from the erosion of the sediment bank.

These eroding sediment bank shorelines border land that is in greatest demand for homesites. Low sediment bank shorelines (less than 5 feet) are the most common type of sediment bank.

Organic Shorelines

Approximately two thirds of North Carolina's estuarine shoreline is dominated by the vegetative growth of swamp forests and marsh grasses. Organic shorelines are characterized by peat sediment composed of organic matter with varying amounts of fine sand and mud.

Estuaries and Development

Most estuarine shorelines in North Carolina are actively eroding, although erosion rates range from a few feet per decade in the innermost and small tributary estuaries up to an average of 3 feet per year in exposed low sediment banks and marsh peats in the outer estuaries.

Actual erosion rates for a specific stretch of estuarine shoreline is highly variable and depends on many factors, including:

- Fetch – the average distance of open water across which the wind can blow in front of the shoreline
- Water depth, bottom slope and beach – bottom characteristics of the nearshore area and the presence and width of a sand beach between the eroding sediment bank and shoreline
- Bank height and composition – height of the sediment bank at or immediately behind the shoreline and the hardness of the sediments or rocks that compose the bank
- Vegetation – type and abundance of vegetation occurring on the sediment bank and shoreline, and in the offshore area
- Shoreline geometry, orientation and geographic location – general shape of the shoreline, direction the shoreline faces and geographic location within the estuarine system

Most estuarine shoreline erosion takes place in direct response to high-energy storm. Therefore, the amount of recession at any location is quite variable from year to year and depends on the frequency of storms; the type and direction of approach of any given storm; the intensity and duration of each storm; and the resulting wind tides, currents and waves produced by that storm.

North Carolina Inlets

Inlets are waterways between islands, or spits, that serve as passages through which sediment is transported. There are 23 inlets along the North Carolina coast. Four of these inlets are located north of Cape Lookout and the other 19 are to the south.

The northern inlets along the Outer Banks are characterized as being wave-dominated with large flood tidal deltas. The tidal range for this region is microtidal (0-2 m). Historically there have been many inlets that have migrated up and down the Outer Banks. All were created by storm processes and continue to be dominated by storm breaching.

The 19 inlets to the south of Cape Lookout are traditionally smaller migrating inlets that are dominated by tidal and as well as wave processes. Many of the inlets in southeastern North Carolina are maintained by the US Army Corps of Engineers for navigational purposes. Others are in a natural state and behave in response to amount of sediment available to the inlet system, tidal prism, wave action and longshore currents.

In microtidal areas, such as North Carolina, sediment normally does not flow very far seaward. Rather, flat areas of sand are deposited on the landward side of the inlets forming extensive flood tidal deltas. The combination of shifting sediment, tidal action and waves causes many inlets to constantly change position. As a result, tidal deltas, as well as areas of land located on either side of inlets, are highly unstable and can change their profiles in response to even minor changes in the inlet.

Because of their complex nature and scales of motion and geomorphic change - which range from seconds to centuries - little is known about fundamental processes such as short- and long-term migration trends and cycles of an inlet, stability of the navigation channel, shoreline change within and near an inlet, the response of inlet shoaling to varying wave and current conditions and the distribution of sediment transport within the inlet proper.

What's Happening to the Barrier Islands Today?

Something fundamental has occurred within the last few hundred years. Virtually all barrier islands in the world are eroding. On islands with open water (as opposed to salt marsh or mangroves) behind them, erosion is occurring on the sound side. It is clear from observations on undeveloped barrier islands that barrier islands are slimming down, even including those islands that were building seaward just a millennia ago.
Two causes have been suggested for the narrowing of barrier islands. One is that man, by damming rivers, jettying inlets, seawalling beaches and dredging channels and harbors has precipitated a sand crisis. This shortage of sand is causing worldwide erosion.

Another view is that island thinning is due to sea level rise. If this is the case, the narrowing distances between ocean and sound will facilitate rapid and frequent cross-island overwash and allow efficient and rapid island migration in the future. Thus the islands may be effectively preparing for the upcoming acceleration in the rate of sea level rise. Very likely, both of the suggested causes are behind the worldwide erosive state of barriers.

Island Migration

Island migration is an amazing geologic phenomenon. It wasn’t even recognized until a couple of decades ago. During the l930s and '40s shoreline erosion was very evident on the NC Outer Banks and a massive dune building effort was begun to save them. A continuous dune was constructed almost from the Virginia border to well beyond Cape Hatteras. It made perfect sense to do this in the context of the prevailing ideas about barrier islands. It soon became apparent that the islands were not eroding, but migrating, with shoreline erosion a part of the process.

Island migration involves three fundamental processes: l) open ocean shoreline retreat, 2) sound-side widening by overwash on the sound shoreline, and 3) raising the elevation of the island by overwash.

Ocean side shoreline retreat is due to a number of factors, some of which remain unknown. These factors include a myriad of human activities which effect sand supplies plus the ongoing relative sea level rise. The sound side widening process is carried on via a number of processes. On Masonboro Island, storm waves from Hurricane Fran washed over the narrow (less than 100 meters) island and deposited a series of sand fans on the salt marsh behind the island, thus widening the entire island in a matter of hours. Another widening process occurs when inlets close. The flood tidal delta, the body of sand pushed into the sound by tidal currents while the inlet existed, is built up and attached to the island by the sediment accumulating ability of salt marshes or mangroves. If the inlet migrates, then the island is widened along the distance of inlet migration. This distance may be measured in miles in a time frame of a century or more.

A key element of island migration and evolution is sand supply. Every grain of sand on a barrier island came across the beach at one time or another. Each grain came onshore either by being blown there or by being washed there by storm waves and floods.

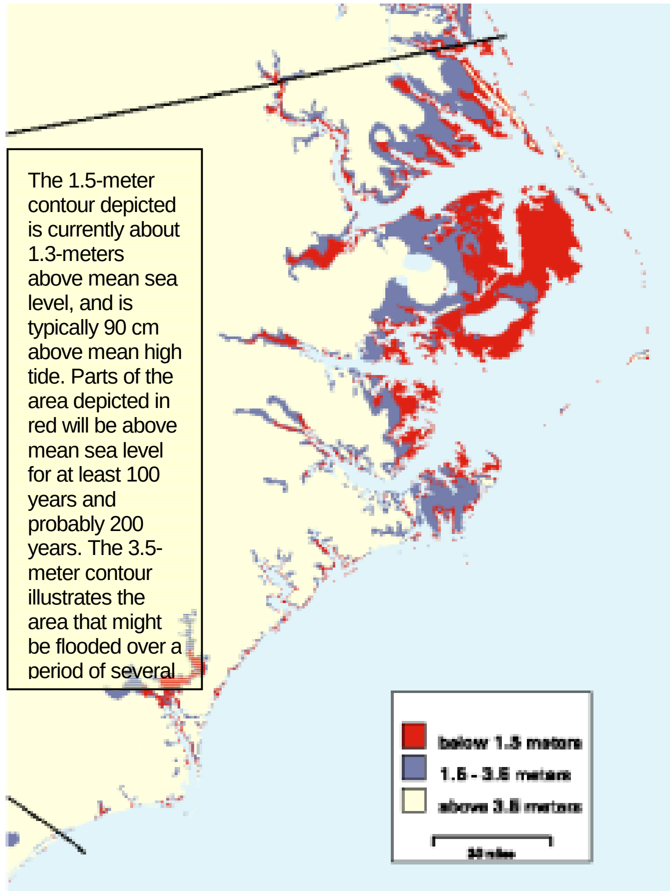


Figure 6 - Lands Vulnerable to Sea Level Rise

As the islands migrated up the coastal plain they left behind on the continental shelf a blanket of sand that was once beach or island sediment. Thus a continuous supply of fresh sand was needed to maintain the island. Geologists believe that this sand is obtained by the continuous capture of former river sand, once deposited at the heads of estuaries and eventually overrun by the moving islands. This sand, which often contains seashells of organisms that live only in the sound (such as oysters), is contributed to the barrier island by a process described as shoreface bypassing.

Through this process, old river or sound sand passes to the innermost continental shelf as the barrier island moves over it. Shoreface bypassing occurs mostly as a result of storm erosion of the shoreface. Between storms, waves gradually push the newly churned up sand, complete with its fossil shells, up to the beach.

In some instances, particularly well illustrated on Cedar and Masonboro Islands, salt marsh muds that formed on the sound side of the island crop out on the beach. These occurrences, as well as the ubiquitous presence of oyster shells on many barrier island beaches, prove that barrier island migration is for real.

What does the mainland do while islands are migrating? Needless to say, the mainland shoreline must move back or the islands will no longer be islands. In fact, once in a while the migrating islands do catch up with and smash into the mainland. This is what has happened at Myrtle Beach, SC. Here the mainland fronts the open ocean. Given enough time and enough sea level rise, it is probable that the island will break away from the mainland a few thousand years from now.

CHAPTER 2: Coastal Hazards and Hazardous Processes

The coastal landscape is an evolving, dynamic balance between sediment supply, wave energy and sea level change. As more and more people live and build in the coastal zone, the potential for property damage and loss of life increases summarily from hurricanes, nor'easters and even minor storms.

This section presents an analysis of the natural phenomena that constitute hazards along the North Carolina coast. The next sections describe the geomorphologic features that influence the impacts that natural phenomena have on North Carolina's coastal communities.

What are Natural Hazards?

A widely accepted definition characterizes natural hazards as "those elements of the physical environment, harmful to man and caused by forces extraneous to him" (Burton, 1978). More specifically, the term "natural hazard" refers to all atmospheric, hydrologic, geologic and seismic phenomena that, because of their location, severity and frequency, have the potential to adversely affect humans, their structures and their activities. Natural coastal phenomena include periodic extreme storm events, such as hurricanes and severe mid-latitude cyclones, and ongoing processes such as winds, waves and storm surge

The term "natural" eliminates such manmade phenomena as war, pollution and chemical contamination as well as hazards not necessarily related to the physical environment such as infectious disease.

How Natural are Natural Hazards?

Not withstanding the term "natural," a natural hazard has an element of human involvement. Without the human-built environment to interact with, for example, coastal storms drive process that create and shape the natural shore zone.

A **physical event,** such as a hurricane that impacts an undeveloped barrier island, that does not affect human beings is a **natural phenomenon** but not a natural hazard. A natural phenomenon that occurs in a populated area, however, is a **hazardous event.** A hazardous event that causes unacceptably large numbers of fatalities and/or overwhelming property damage is a **natural disaster.**

Hazardous Events

Hurricanes and northeasters have played important roles in the modification of the shoreline. The present shoreline is, in fact, mainly the result of erosion and deposition caused by these storms. A sever northeaster or hurricane can cause as much of an impact to the shore in a matter of a few hours as it would take normal weather conditions to produce in a hundred years (LIRPB, 1984).

Hurricanes and Tropical Storms

Hurricanes are tropical depressions which develop into severe storms characterized by winds directed inward in a spiraling pattern toward the center. They are generated over warm ocean water at low latitudes and are particularly dangerous due to their destructive potential, large zone of influence, spontaneous generation and erratic movement. Phenomena associated with hurricanes include:

- Winds exceeding 64 knots (74 mi/hr or 118 km/hr). Hurricane damage results from the direct impact of wind' on fixed structures and from wind-borne objects (See Appendix I for more information).
- Heavy rainfall that commonly precedes and follows a hurricane for up to several days. The

quantity of rainfall is dependent on the amount of moisture in the air, the speed of the hurricane's movement and its size. On land, heavy rainfall can saturate soils and cause flooding due to excess runoff (land-borne flooding) and damage crops by weakening support for the roots.

North Carolina has experienced 275 tropical cyclone days (days that a storm has affected North Carolina) since 1800 (NWS, 2000). The total tropical cyclone days and percentage of occurrences by month is presented in the table below.

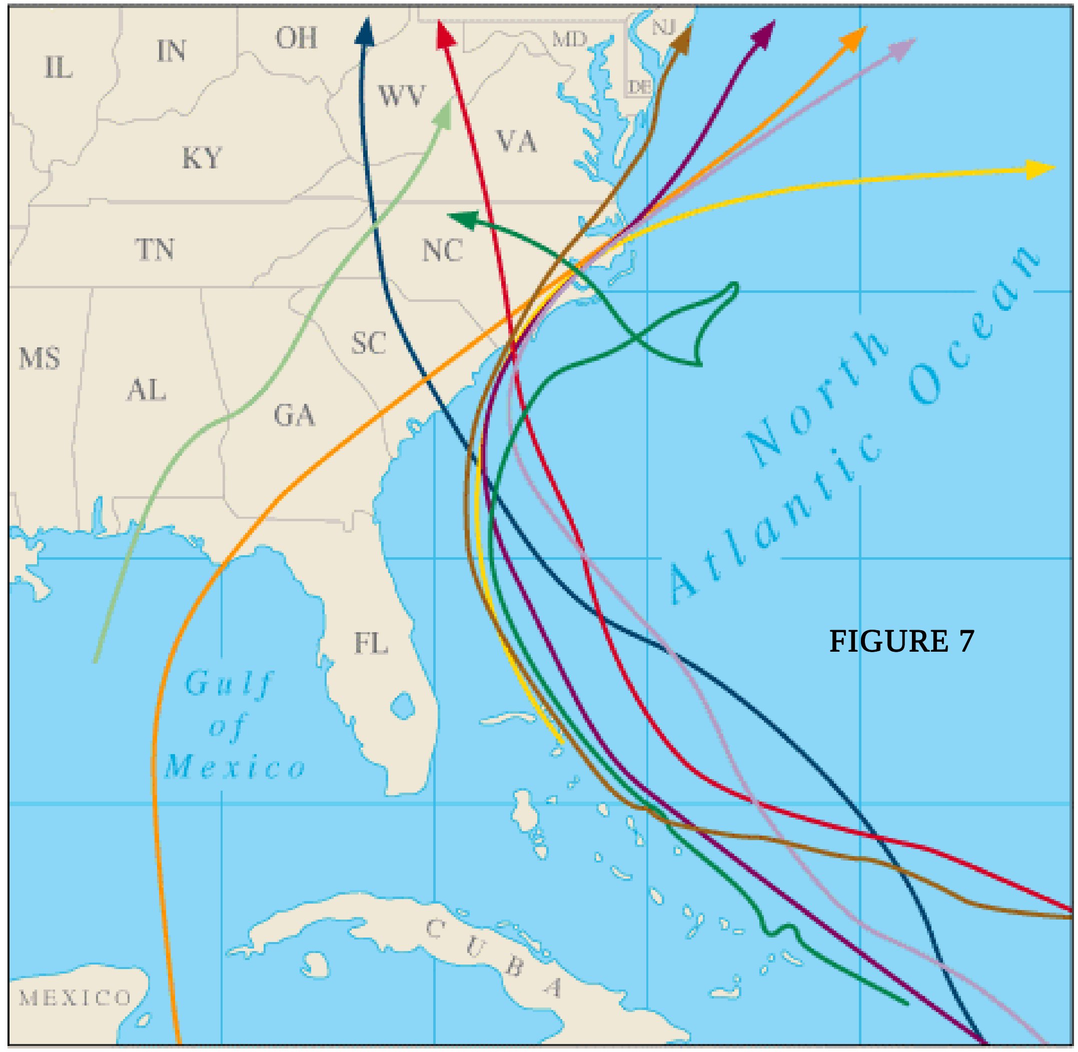
June:	23 Tropical cyclone days	8.4%
July:	16 Tropical cyclone days	5.8%
August:	65 Tropical cyclone days	23.6%
September:	103 Tropical cyclone days	37.5%
October:	62 Tropical cyclone days	22.5%
November:	5 Tropical cyclone days	1.8%
December:	1 Tropical cyclone days	0.4 %

Tropical Cyclone Days and Percentage of Occurrences By Month

(Note that 81.1 % of the tropical cyclone days occurred from mid August through October. See Appendix II for more information).

Mid-Latitude Storms (Extra-Tropical Cyclones)

Mid-latitude storms (often called nor'easters) are low pressure systems with associated cold fronts, warm fronts, and occluded fronts that typically cover larger areas, have much lower wind speeds and move slower than urricanes. Mid-latitude storms sometimes remain off the coast for several days. Unlike fast-moving



N.C. Landfall Hurricanes

Floyd, 9/16/99 · Bonnie, 8/26/98 · Bertha, 7/13/96 · Allison, 6/4/95 · Hugo, 9/22/89
Dennis, 9/4/99 · Fran, 9/6/96 · Arthur, 6/19/96 · Beryl, 8/16/94

Source: U.S. Department of Commerce. National Hurricane Center.

hurricanes, the winds and waves of a mid-latitude storm may persist through several tidal cycles, amplifying shoreline impacts due to waves at any given location.

Mid-latitude storms get their energy from the horizontal temperature gradients that exist in the atmosphere. The ideal breeding grounds for a mid-latitude storm are coastal areas where a large wintertime temperature difference may exist between air over the cold continental land and the relatively warmer ocean waters. The key to a low pressure center growing into a full-fledged mid-latitude storm is the front (temperature gradient) between polar air from the north and tropical air from the south.

The presence of a strong high pressure system in eastern Canada can block a nor'easter from moving quickly up the East Coast, giving a storm more time to gather strength (Pilkey, 1998).

Considering their size, number and duration, mid-latitude storms pose a serious threat to barrier island development.

Hazardous Processes

Most, but not all, potentially hazardous coastal processes are associated with hazardous events. The most important processes that impact North Carolina are wind, waves, coastal and inlet currents, storm surge flooding and storm surge flood and ebb currents.

Coastal storm processes rarely act separately. Wind, waves and currents can all be active at the same time and combine to form secondary processes. For example, storm surge is formed by several processes acting together, any one of which may be dominant during any given storm or for a given period during a certain storm: wind and waves push water toward shore, low pressure allows doming of the sea surface and rotating winds can cause shallow near shore water to flow unpredictably.

Because hazardous events produce the processes which impact coastal communities; it is the processes – and not the events themselves – to which coastal communities are vulnerable, and which coastal hazard mitigation strategies must address.

Wind

The most common and, often, most costly hazardous coastal process is direct wind impact on structures, including flying debris (known as missiling). Strong winds can also destroy vegetation by uprooting and knocking over trees, defoliating trees and other vegetation, blowing down shrubs and grasses and by damaging leaves directly - either by blasting leaves with airborne sand and/or by carrying damaging salt spray inland (the same salt spray pruning effect that produces the near-shore sloping profile of maritime vegetation will kill or damage inland vegetation that is not salt tolerant). Storm winds can also be responsible for transporting sediment onto and off a barrier island.

Hurricane winds are generally categorized in terms of the pressure they exert. Pressure varies with the square of the velocity of the wind and a doubling of wind velocity corresponds to a four fold increase in pressure. For example, a 50 mph wind exerts a pressure of about 10 psf (pounds per square foot) on a flat surface. A 100 mph wind would exert a pressure of 40 psf, and a 200 mph wind would exert a pressure of 160 psf (Pilkey, 1996).

The areas impacted by hurricane-force winds are usually within 20-30 miles of the track of the eye. Considering that the diameter of a hurricane ranges from 60 to 1,000 miles, and that gale-force winds may extend over most of this area, the total energy released over the thousands of square miles covered by the storm is almost beyond comprehension.

Hurricane damage (experienced along the US mainland) does not increase linearly with wind speed. Rather, damage increases exponentially with wind speed, and a 148 mph hurricane (category 4 on the Saffir-Simpson Scale) may produce - on average - up to 250 times the damage of a minimal category 1 hurricane (Pielke and Landsea 1998).

Waves

Waves can damage property by direct attack or by pummeling structures with floating debris (a process called ramrodding).

Depending on the track of a given storm, waves can approach the coast from almost any direction. If a storm passes along the coast, or at a low angle to the coast, the time-averaged effect means that each point along the coast will be subjected to the same forces. The maximum height to which wind-generated waves will grow is controlled by three factors:

1. Velocity of the wind,
2. The area expanse over which the wind blows (fetch) and
3. Length of time the wind blows.

The wave height limit is essentially the extent to which energy from the wind can be transferred by friction to the water surface. In the relatively simple case of a major winter storm, the long fetch (hundreds to over a thousand miles) and duration (up to several days) means that the maximum wave heights for that given wind speed will develop. This condition is called a fully developed sea.

The force of a wave may be understood by considering that a cubic yard of water weighs more than three-fourths of a ton, about 1,500 lbs. Because a breaking wave can move shoreward at a speed of 30 or 40 mph, waves can be one of the most destructive elements of a hurricane. A 10-foot wave can exert more than 1,000 pounds of pressure per square foot, and wave pressures higher than 12,000 psf have been recorded.

Storm Surge

A storm surge is an abnormal rise in sea water level associated with a hurricane or other storm at sea. The term "storm surge" is technically defined as *"the super-elevation of the still-water surface that results from the transport and circulation of water induced by wind stresses and pressure gradients in an atmospheric storm*" (Pilkey, 1998).

A rule of thumb is that a 1 millibar change in air pressure translates into a change in sea level of about 1 centimeter. While this may not appear to be significant, it is important to understand that a Category 5 hurricane can have a central pressure of less than 920 millibars - almost 100 millibars lower than the normal atmospheric pressure of 1,013 millibars. This difference means that almost one full meter of storm surge can be due to atmospheric pressure differences as a storm's eye crosses a shoreline.

Storm Still-Water Surge Levels (in Feet Above Mean Sea Level) for 25-, 50- and 100-year Storms

	25	50	100
Virginia to Cape Hatteras	7.43	8.20	8.80
Cape Hatteras to Cape Lookout	7.10	7.63	8.00
Cape Lookout to New River Inlet	7.63	9.33	10.95
New River Inlet to Cape Fear	8.80	10.55	12.05
Cape Fear to South Carolina	9.67	11.23	12.45

Note: "still-water surge level" is the height to which the sea rises during a storm, and does not include the height of waves.

Although storm surge is caused by strong on-shore winds and/or intense low pressure cells and ocean storms, storm characteristics alone do not determine storm surge elevations. Water level is controlled by a complex combination of wind, atmospheric pressure, existing astronomical tide, waves and swell, local coastal topography and bathymetry and the storm's proximity to the coast.

Together, these factors create a mound of water, the crest of which lies to the right of the hurricane center near the position of maximum winds. The most common impacts associated with storm surge include:

- Wave impact and the physical shock on objects associated with the passing of the wave front.
- Hydrostatic/dynamic forces and the effects of water lifting and carrying objects.

Indirect impacts include flooding and undermining of major infrastructure such as highways and railroads.

Storm Surge Ebb Flow

The counterclockwise circulation in tropical cyclones is responsible for abrupt changes in wind direction and intensity during storm passage. As a storm passes landward across a barrier coastline, this circulation pattern produces abnormally high water-level differences between ocean and sound.

For a hurricane moving perpendicular to the Atlantic coast toward a barrier coastline, the initial winds of the storm are onshore to alongshore. Elevated water levels occur along the front of the barrier and on the mainland side of the sound. After passage of the storm center, an offshore wind will result to the left of the eye and an alongshore wind to the right of the eye.

If the forward motion of the storm is rapid, reversal of wind direction is abrupt, giving rise to abnormally high storm-surge ebb against the back side of the barrier island at the same time sea level on the ocean side is low as winds push the water seaward. These conditions lead to flood flow across the island in the seaward direction, resulting in erosive scour and the potential for new inlet formation.

Storm surge ebb is not a dominant process in all hurricanes, but its intense scouring during Hurricane Hugo, for example, was responsible for significant property damage to buildings, seawalls, roads and utilities. Ebb scour channels, eroded through washover deposits, indicated that the process was separate from, and took place after, the erosion and deposition induced by storm surge and waves.

Surge elevations and ebb flow velocities are influenced by several factors including the shape of the ocean or estuarine shorelines (concave or convex), the presence or absence of estuarine vegetation, wind speed, storm duration and the direction of storm movement.

Rain (Falling/Rising Water)

On an undeveloped barrier island, rainwater generally seeps into the ground or drains toward open water. As an island is developed and land is covered with buildings and pavement, the amount of permeable land surface exposed to absorb rainfall is reduced, and runoff increases. On barrier islands with dense urban development, or areas where the contour of the land has been altered, storm runoff does not follow the natural course and can create a washout resulting in flooding of shorefront property. In addition, the washout exposes land and buildings behind the dunes to further flooding by storm surge.

Shoreline Movement

Changes in shoreline position result from beach-ocean interaction coupled with human activity. Wind, waves, and longshore currents are the driving forces that determine shoreline position, and the removal and deposition of sand permanently changes beach shape and structure. During a storm, sand may be transported to land-side dunes, deep ocean trenches, other beaches and deep ocean bottoms.

A migrating shoreline poses many problems for a coastal community in that property is frequently lost to the dynamic beach-ocean system. Additionally, human activity may accelerate the process of coastal erosion through poor land use decisions.

Currents

Storm-generated currents are responsible for moving vast amounts of sediment, water and storm debris both parallel and perpendicular to the coast. By far, the greatest volume of water during a storm is moved alongshore as storm waves approaching the shore at an angle set up a current in the general direction of wave travel. This phenomenon is known as a longshore current. Storm currents are often reinforced – or diminished – by wind friction.

Because storm waves are so large, they begin to break much farther from shore than normal or fair weather waves. The net effect is a widening of the surf zone. When the surf zone is widened, more sand is forced into the water column and more water and sand is moved parallel to shore. A strong longshore current can move sediment (and storm debris) out of one local area and into another, resulting in a permanent loss of sediment.

Storms are also responsible for a variety of bottom currents that move at high angles, sometimes perpendicular to the shoreline. Bottom currents are due to the local rise in sea level caused by the storm surge. Because surge sets up a sea surface that is actually tilted away from land, the water above normal sea level tends to flow “downhill” and back out to sea.

Bottom currents, while not usually very strong or common, can be responsible for moving great quantities of sediment in short periods of time away from the beach and into deeper water where it may be permanently removed from the beach system.

Inlet Dynamics

Currents and patterns of flow (channel positions) in tidal inlets may be modified by the combined effects of storm surge, stage of tidal cycle, increased rainfall runoff and ebb scour.

Changes in channel positions during storms may cause erosion of, or deposition on, adjacent islands.

To understand how hazardous coastal events impact coastal communities, we must first understand the interactions between natural processes, landforms, their sediments and vegetation; and then the mechanics of the actual event.

Figure 8: Storm Overwash from Tropical Storm Dennis Between Two Buildings in Kill Devil Hills, NC

CHAPTER 3: Coastal Hazard Geoindicators

No locality along the coast is truly safe. Hurricanes, floods, wind, waves, erosion and inlets can impact any community. In addition, human activity almost always reduces the relative stability of the natural environment.

Human-built structures are static, and when placed in a dynamic system, they tend to disrupt the balance of that system. Interference with sand supply, the disruption of vegetative cover, topographic alterations and the effects of other structures can actually create conditions that increase vulnerability.

The concept that different parts of a community respond differently to similar coastal processes is fundamental to the development of an effective hazard mitigation strategy. While many natural events and processes are potentially hazardous to development along the North Carolina coast; the type, extent and degree of impacts that these processes will have are dictated by a set of local geologic, environmental and morphologic features collectively known as geoindicators.

This section provides an overview of the most common types of geoindicators found along the North Carolina coast. The next section discusses how PSDS uses these geoindicators to assess coastal vulnerability.

Geoindicators

The International Union of Geological Sciences (IUGS) defines geoindicators as "measures of surface or near-surface geological processes and phenomena that vary significantly over periods of less than 100 years and that provide information that is meaningful for environmental assessment" (Bush, 1999).

Berger notes that geoindicators identify a minimum set of parameters that describe short-term environmental dynamics and are proxies representing all the parameters on which processes depend. As a result, geoindicators can provide managers with simple, qualitative tools for rapid identification of vulnerability that is scientifically valid (Bush, 1999).

Coastal geoindicators are geomorphologic features that influence coastal processes and determine how a community will respond to, and recover from, different coastal processes. Because of their role, geoindicators provide a management tool for the assessment of vulnerability and risk, either as a supplement to long-term environmental auditing and monitoring, or for initial coastal assessment as in developing countries.

Most geoindicators are best evaluated in the field, although much information may be drawn from other existing sources such as maps, orthophotographs, videos and erosion rate documentation. Using examples of barrier and mainland coasts, indicators of process/response are examined regionally, locally and site-specifically: the latter being the primary influence upon individual properties.

Natural Clues to Vulnerability

Coastal geomorphology is controlled by a wide range of geologic and climatic factors and processes operating at a variety of scales. The frequency, intensity and location of active physical processes (and events) are controlled by regional factors (seismic setting and latitude), local factors (protective offshore barriers and coastal configuration) and site-specific factors (elevation and vegetation). Geoindicators tend to focus on the local and site-specific factors that show the less-than-100 year variation.

A number of environmental features provide clues to a community's active physical processes, its natural history and associated natural hazards. A critical observation of each feature can help assess the relative intensity of various processes that have acted in the past and, therefore, provide an indication of the level of vulnerability associated with development in a community.

Regional Factors that Determine Vulnerability

A quick look at a coastal community's regional geologic and oceanographic setting can give insight into the types of processes that should be active in an area. The regional setting, in part, determines vulnerability.

For example, latitude will determine some climatic and oceanographic factors such as wind and wave patterns, currents and susceptibility to hurricanes. The oceanographic setting of the adjacent continental shelf and regional coastal configuration will influence the distribution of energy reaching a shoreline (narrow shelves allow more wave energy to reach a coast, but a wide shelf may increase the potential elevation of storm surge flooding).

The presence of local natural offshore features such as sand bars or reefs may dissipate wave energy and afford some natural protection. The geologic setting will determine whether shorelines are rocky and resistant or are composed of unconsolidated, erodible material.

The configuration of the shoreline can also play an important part in increasing or reducing the intensity of various coastal processes and vulnerability. An embayed coast, for example, may be somewhat protected from intense wave attack during a storm, although storm surge flooding may be magnified as surge waters are funneled up the embayment. A convex coast, on the other hand, is not at risk for storm surge amplification although it is likely to experience focused wave energy.

Local Factors that Determine Vulnerability

Site-specific factors are the primary indicators of the hazards likely to impact a community. The shoreline type existing in any particular area is a function of rock or sediment type, the landforms being deposited or eroded by the waves, their storm response, the dominant direction of wave approach, wave heights, elevation and human influence. Geoindicators are divided into four groups: 1) topographic, 2) shoreline, 3) inlet and 4) other.

Topographic Geoindicators

Elevation

Site elevation is a primary determinant of susceptibility to inundation. Elevation above sea level and elevation above ground level are also important determinants of vulnerability because they have a direct influence upon wave action, storm surge and storm surge ebb flow.

The specific critical elevation will vary between locations depending on regional flood experience and predicted levels of storm surge.

Vegetation

Vegetation has a significant influence on coastal processes. Vegetation, for example, traps sediment, stabilizes barrier islands and coastlines, provides a protective barrier against wind, stimulates growth of certain dune grasses and can decrease storm surge and ebb flow velocities. The presence of well-developed areas of shrubs and trees, especially high on the backshore of a beach, suggests low erosion potential and infrequent salt water intrusion.

Grasslands

Grassland ecosystems are located behind the dune ecosystem. It occupies areas that are moister and lower than the dunes. The vegetation consists primarily of grasses, sedges and occasional shrubs. Grasslands are rarely flooded by tidal water although high spring or wind tides may flood from the sound side. Most grassland plant species are able to survive short periods of salt water flooding.

The dominant grass and sedge species in grassland ecosystems include salt meadow cordgrass, little bluestem, muhly, bulrush, Fimbristylis, finger grass and love grass. Important broadleaf species include pennywort, Sabatia and seaside goldenrod.

Shrub Thicket

Shrub species such as wax myrtle, marsh elder and sea ox-eye usually invade areas where vegetation has been established for a long period of time. These areas may eventually form a dense thicket of shrubs and even a maritime forest. The thickets may be impenetrable or scattered. Shrub thickets grow on the edges of maritime forests, on old stabilized dunes and in dune swales. In closed thickets, the ground is nearly barren of herbaceous vegetation due to the lack of light penetration. Within more open thickets, grassland vegetation or black needlerush marsh may be interspersed among the patches of shrub.

Shoreline Geoindicators

Dune Parameters

The ability of a frontal or primary dune to absorb incoming wave energy is directly related to the dune's height and width. High, continuous, heavily vegetated sand dunes at the back of the beach are evidence of a stable or accretionary shoreline. Bare scarps at the back of the beach indicate very recent wave or storm surge erosion, and dune protective capability is reduced until sand accumulates and dunes are rebuilt. Dune breaches, breaks and gaps, such as those cut to allow for emergency vehicle access, will decrease the natural protective features of a dune.

Dune Escarpment

In most cases, the shoreline is the least stable component of the coastal environment and receives the greatest management attention because of potential real estate loss and property at risk located near the shoreline. Although some shorelines are stable, erosional shorelines are more common. The rate at which an ocean or estuarine shoreline is eroding - or accreting - is an indicator of vulnerability because it illustrates whether sediment is being lost from, or added to, a shoreline over time.

Long term average erosion rates may fail to illustrate acute, and often significant, changes caused by individual storm events. Post-storm field assessments are used to help document these changes. During storms, ancient strata that crop out on the shoreface are eroded, providing an immediate source of "new" sediment to the modern beach. Therefore, the composition of most beaches reflects the composition of ancient sediments eroded from the shoreface.

North Carolina shorelines erode primarily because the supply of new sediment is not sufficient to replace what is removed, and because sand transport mechanisms are being altered by such human activities as dredging.

Bathymetry

Bathymetry, or the nature of the offshore continental shelf, has an important influence on storm surge elevations and wave action. Narrow, steep shelves - such as that found off Cape Hatteras, North Carolina – do not hold much water and will not allow storm surge to pile up. As a result, locations with steep, narrow shelves have inherently lower maximum potential surge elevations than broad shelves. A steep, narrow shelf, however, produces less frictional dampening of wave energy, which means more wave energy is expended on the upper shoreface.

In general, wide shelves mean higher maximum tidal amplitudes and lower wave energy. On narrow shelves, the opposite is true.

Water Exposure

The area of open water a shoreline faces, or fetch, partly determines the size of storm waves that may be experienced. The greater the fetch, the larger the wave-making potential. In mesotidal barrier-island systems, back-barrier tidal creeks and channels often erode the backside of a barrier island as fast as open-ocean waves erode the front side.

Beach Width

The width of the dry beach at high tide is another measure of vulnerability. A flat beach, often found after a storm, can be explained in terms of the dynamic equilibrium. An increase in wave energy, along with a rise in sea level associated with storm surge, moves sand and changes the shape of the beach. Departing storm waves take sand from the upper beach or from the first dune and transport it to the lower beach.

In North Carolina, most beaches respond to a storm by flattening, which causes storm waves to expend energy over a broader and more level surface. In a major storm, the surf zone sand is sometimes transported beyond the base of the shoreface and is lost from the beach forever, and an island can lose a great deal of sand during a storm. Sand that remains in the shoreface system can, however, return as it is gradually pushed shoreward by fair weather waves. Due to the presence of longshore currents - produced by waves that approach the shore at an angle, sand may be deposited miles from where it was originally removed. Nourished beaches, and those with engineered structures such as sea walls and revetments, generally recover much less sand than natural beaches.

Generally speaking, a dry beach width of at least 20 feet is needed to dissipate and reduce incoming storm wave energy.

Storm Overwash

When the height of approaching storm waves exceeds the height of depressions along the dune ridge, water overflows the low points and washes down the landward side of the dunes, eroding sand and carrying it inland.

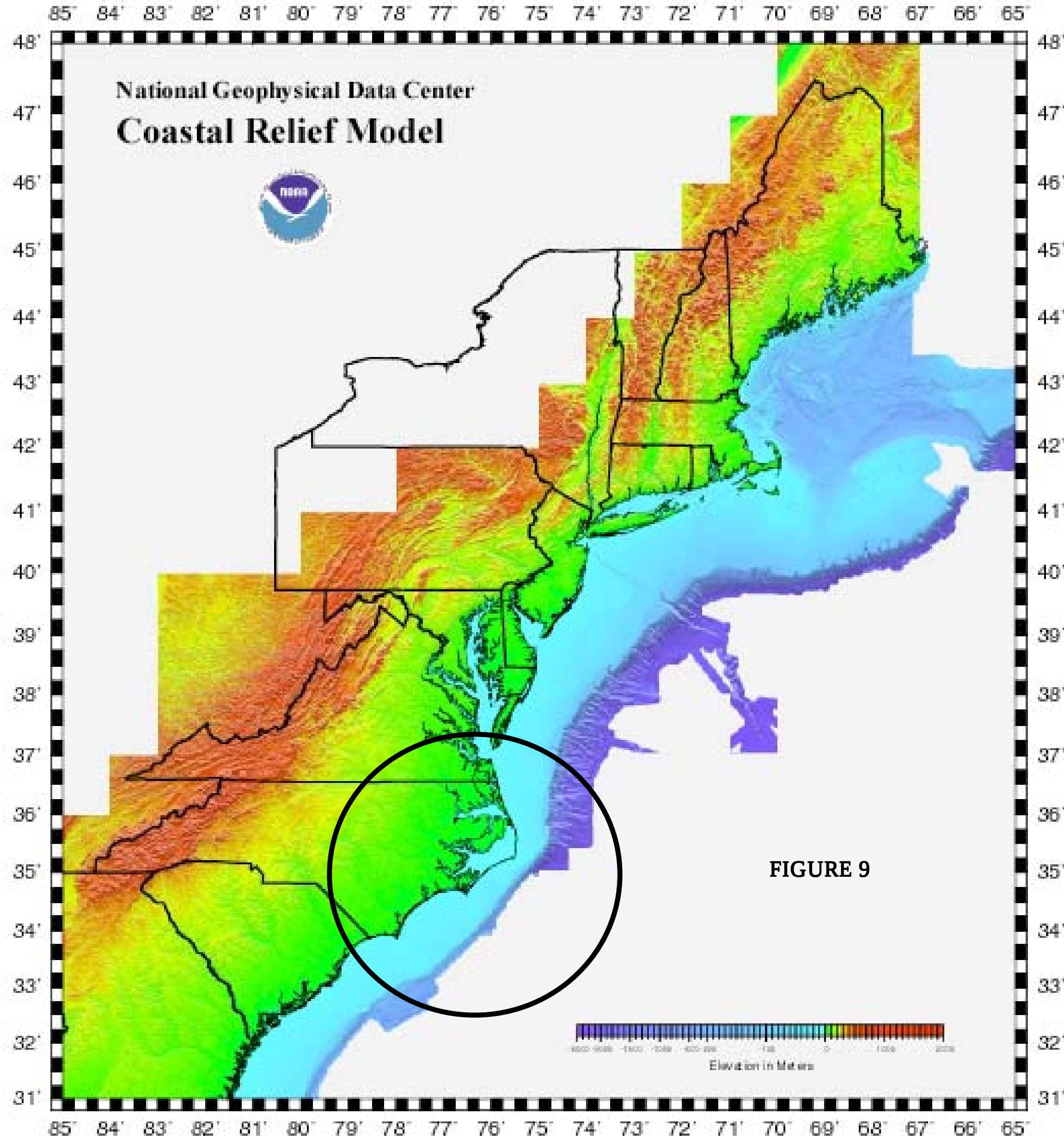
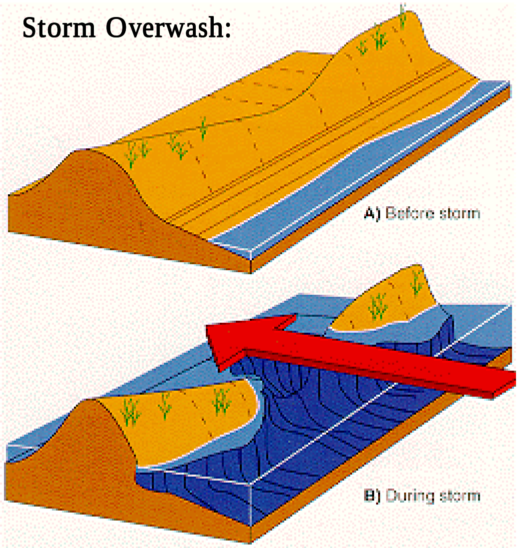


FIGURE 9

These washover areas deepen and widen under continual wave attack, allowing larger volumes of water to spill across the dune line and flow farther inland. Eroded sand may be deposited behind the dunes or carried into the middle of the island. In very severe storms, washover waters may even reach the back side of the island.

Storm Overwash:

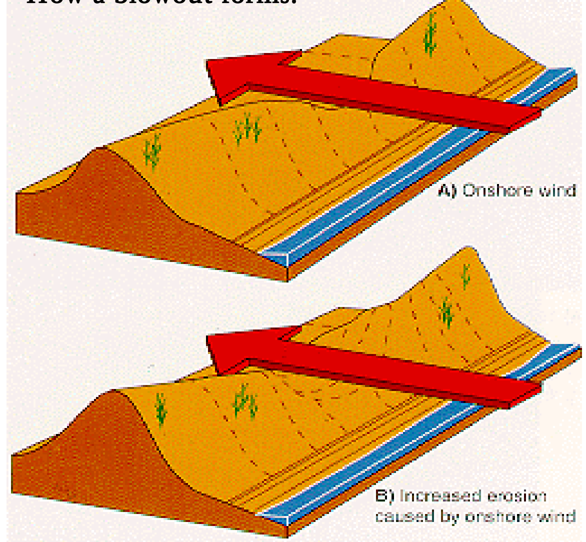


Areas of frequent major washovers may regenerate dunes slowly due to the volume of sand removed through erosion and because vegetation has been scoured.

Dune development may be impeded if the sand in a washover is too wet to be blown by the wind. Evidence of hurricane washovers is apparent on many North Carolina barrier islands.

Overwash fans develop when water thrown up by waves and storm surge flows between and around dunes. Surge waters carry sand and stained, bleached and natural-colored shells that are deposited in flat, fan-shaped masses. Sand from these fans forms and maintains dunes and builds island elevation. When overwash fans are extensive, they may overlap and form sheets called overwash terraces.
Storms may also produce washouts in dune areas. These are similar to washovers, differing primarily in the direction of eroding waters. If there are breaches or depressions in the dunes, rainwater that collects in the swales (valleys between the dunes) may be channeled through these low points and overflow back onto the beach, carrying sand with it.

How a blowout forms:

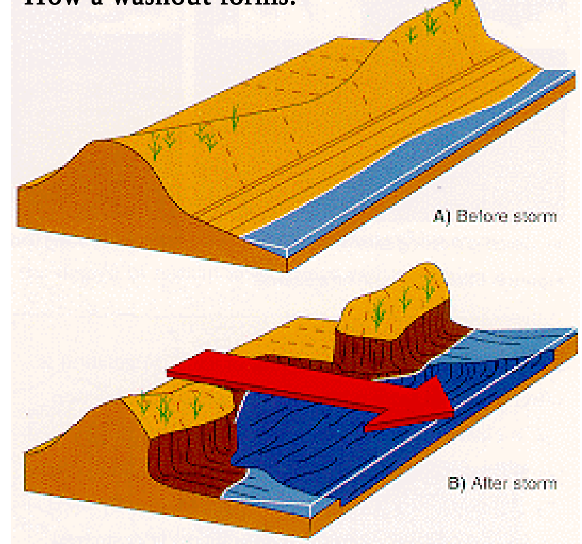


Washouts may also be formed by retreating sound waters. Hurricanes, particularly slow-moving ones, may pile water into the sounds. If natural channels such as inlets are too narrow to accommodate water retreating from the sounds, washouts may cut across the low areas of least resistance in the barrier islands.

Blowouts are breaches in the dunes caused by wind erosion. They are usually aligned with prevailing northeasterly winds and may be cut down to the water table. During storms, blowouts may become channels for storm-surge waters from the sounds.

The presence of overwash fans, overwash aprons, overwash terraces, washouts and

How a washout forms:



blowouts indicate active sediment transport and deposition. These features are used to help assess historic storm impacts and predict future responses.

Engineering Structures

The presence of an engineered structure such as a revetment, sea wall or groin indicates that a particular stretch of shoreline is likely being negatively impacted by one or more processes.

Inlet Geoindicators

Potential Inlet Formation

Low, narrow island areas that lack extensive salt marsh and are near the mouths of rivers or estuaries are likely spots for inlet development. Spits are particularly vulnerable to inlet formation.

Barrier islands, particularly low areas in inlet zones, are often breached by mall channels during storms, either by storm-surge flood, or more often, by strong storm surge ebb flow. These channels are not technically considered inlets because they develop and exist only long enough to facilitate interior island drainage. Although these features are usually temporary, they tend to re-appear in the same location.

Inlet Proximity

Once formed, inlets tend to migrate laterally along adjacent barrier islands.
Inlets are highly dynamic features and can influence shorelines some distance away.

Historic/Relict Inlets

The presence of a flood tidal delta can indicate the location of an inlet that is now closed. Inlets that have been artificially closed are almost always unstable areas for development. Some inlets that have closed naturally, however, may be relatively safe because a tidal delta may have increased the island's width enough to promote dune and vegetation growth.

Non-Shoreface Geoindicators

Barrier island features such as sand volume, soil type and the presence of black-stained shells are all indicators of vulnerability. Interior dunes, for example, provide protection from storm surge flooding and waves, and can act as a shield against damaging winds. Black-stained shells, which are characteristic of estuarine and back-island environments, may mean that an inlet was artificially filled with sediment dredged from behind the island (Pilkey, 1998).

CHAPTER 4: Assessing Coastal Vulnerability

The first step in the hazard mitigation process is to identify the natural processes present, or that may affect, the study area. This information can be obtained through a comprehensive literature review, through interviews with residents, state and local decision makers and others and through investigator knowledge and experience. This last element is extremely important because a significant portion of the hazard identification and vulnerability assessment is subjective.

Vulnerability is defined as "being open to attack or damage." Because human coastal development can be attacked and damaged by a variety of natural processes and events (such as hurricanes and tropical storms), it is highly vulnerable. However, where no human interests exist, these same natural phenomena do not constitute hazards nor do they result in disasters. The definition of vulnerability is, therefore, at odds with the perception of natural hazards as unavoidable havoc wreaked by the unrestrained forces of nature. Further, it shifts the burden of "causality" from purely natural processes to the concurrent presence of human activities and natural events.

Unfortunately, human activities along the coast tend to increase the frequency and severity of natural hazards, or cause natural hazards to exist where none existed before. For example, an interior sand dune removed for development reasons can reduce a barrier island's elevation and increase the likelihood for overwash and possible inlet formation. Another example is shoreline migration. Shoreline migration is a natural processes that only becomes a hazard – called erosion - when houses and roads become threatened.

Human intervention can also reduce the mitigating effect of natural ecosystems. The destruction or removal of native island vegetation, which has been shown to reduce wind velocity and water flows, can eliminate a barrier island's primary protective resources and is a clear example of an intervention that diminishes the ability of an ecosystem to protect itself.

Although humans can do little, if anything, to change the incidence or intensity of most natural phenomena, we can play an important role in ensuring that these natural events do not become natural disasters.

This section provides an overview of PSDS' vulnerability assessment methodology and outlines how geoindicators are used to measure, assess and delineate vulnerability in coastal communities.

STEP 1: Acquire Data

The first step in the PSDS Vulnerability Assessment Methodology is the acquisition of relevant data. Existing GIS layers were acquired (A) and additional layers developed (D) using data collected with a Trimble GeoExplorer II hand-held Global Positioning System (GPS) unit. GPS technology was utilized to ensure the positional accuracy of spatial data. The standards of quality required of the data and the methods used to measure quality were explicitly defined before data entry begins.

- Hurricane Storm Surge Inundation Areas
- Q3 FIRM data (A)
- LIDAR elevation data (A)
- Beach access sites (A)
- Population and housing variables (including mobile homes) (A)
- Public water and sewer systems (A)
- Transportation routes (A)
- Average long-term annual erosion rates (A)
- Frontal dune configuration (height, width and distribution) (D)
- Beach characteristics (swash zone width and slope) (D)

- Modern inlet dynamics (D)
- Historic storm responses (D)
- Vegetation distribution, density and type (D)
- Engineered erosion management structures (D)
- 10, 30 and 60 year shoreline positions
- Structure and parcel tax and value data (for Ocean Isle Beach and Nags Head)
- Hurricane Storm Surge Inundation Areas
- Q3 FIRM data
- Beach access sites
- Population and housing variables (including mobile homes)
- Public water and sewer systems
- Transportation routes

Digital hazard/vulnerability maps are then developed using Arc View 3.2 GIS software. Special attention is given to the identification of historic inlet sites, narrow beaches, overwash fans and aprons, storm surge ebb and flow channels, inlets and dune gaps.

STEP 2: Data Analysis

GIS data layers were evaluated to identify the geographic location and spatial distribution of hazard geoindicators, and to delineate vulnerability in each community. Maps that illustrate risk - or the impacts that can be expected from a direct hit from a category three hurricane – were developed for each community. Maps were analyzed to identify specific locations that are more susceptible to the impacts of a category three hurricane, and that may be priority areas for hazard mitigation activities.

Because vulnerability maps are based on semi-quantitative data, the incorporation of specific attributes is largely subjective, and quantitative limits for determining absolute parameters such as dune height, beach width and vegetative density are determined individually for each community.

STEP 3: Vulnerability Assessment

PSDS has developed a Hazard Profile and Vulnerability Matrix that incorporates GIS map data and observational information to help delineate, assess and rank relative levels of vulnerability. Although vulnerability assessments are performed on a community-wide basis, special consideration is given to the presence of local, site-specific geoindicators such as historic inlet sites, narrow beaches, overwash fans and aprons, storm surge ebb and flow channels, inlets and dune gaps that can alter natural processes.

The Hazard Profile

The Hazard Profile (next page) contains a list of all potential hazard geoindicators, with each geoindicator divided into two or three measurable attributes (depending on the specific geoindicator). Each attribute is assigned a hazard level (high, moderate or low) depending on how much influence a specific geoindicator to different physical settings found in the community.

Hazard geoindicator attributes are ranked as being high, moderate or low - in terms of how much influence the hazard geoindicator has on coastal storm processes - with points associated with each ranking (10 for high hazard, 5 for moderate hazard and 1 for low hazard).

The Vulnerability Matrix

After the Hazard Profile is completed, a Vulnerability Matrix (page 10) is developed. The Vulnerability Matrix is used to determine the relative importance that each hazardous event, natural process and Geoindicator has on the vulnerability of the structure, as well as the overall vulnerability of the structure.

The Vulnerability Matrix is divided into four Geoindicator Categories (Topographic, Shoreline, Inlet and Interior) that are ranked, or weighted, based on the influence that the planner (or other expert) feels each has on the overall vulnerability of the structure. The sum of the scores must equal one, and the relative difference among scores reflects the relative weight or influence of each Geoindicator category.

The Geoindicators comprising each of the four Geoindicator categories are then weighted. Again, the sum of the scores of each Geoindicator - within each

Geoindicator category - must equal one with the relative difference among the scores reflecting the relative weight, or influence, of each Geoindicator within each category.

The weight of each Geoindicator category is then multiplied by the weight of each individual Geoindicator to arrive at a normalized weight representing the overall influence of each Geoindicator.

Next, the structure's Hazard Attribute scores are transferred from the Hazard Profile into column eight (entitled "Score") of the Vulnerability Matrix. Each Geoindicator's normalized score is then multiplied by the structure's Hazard Attribute score to obtain a Final Score. The sum of the Final Scores is the vulnerability of the structure. In this example, the structure received a score of 7.78, which means the structure is Extremely Vulnerable.

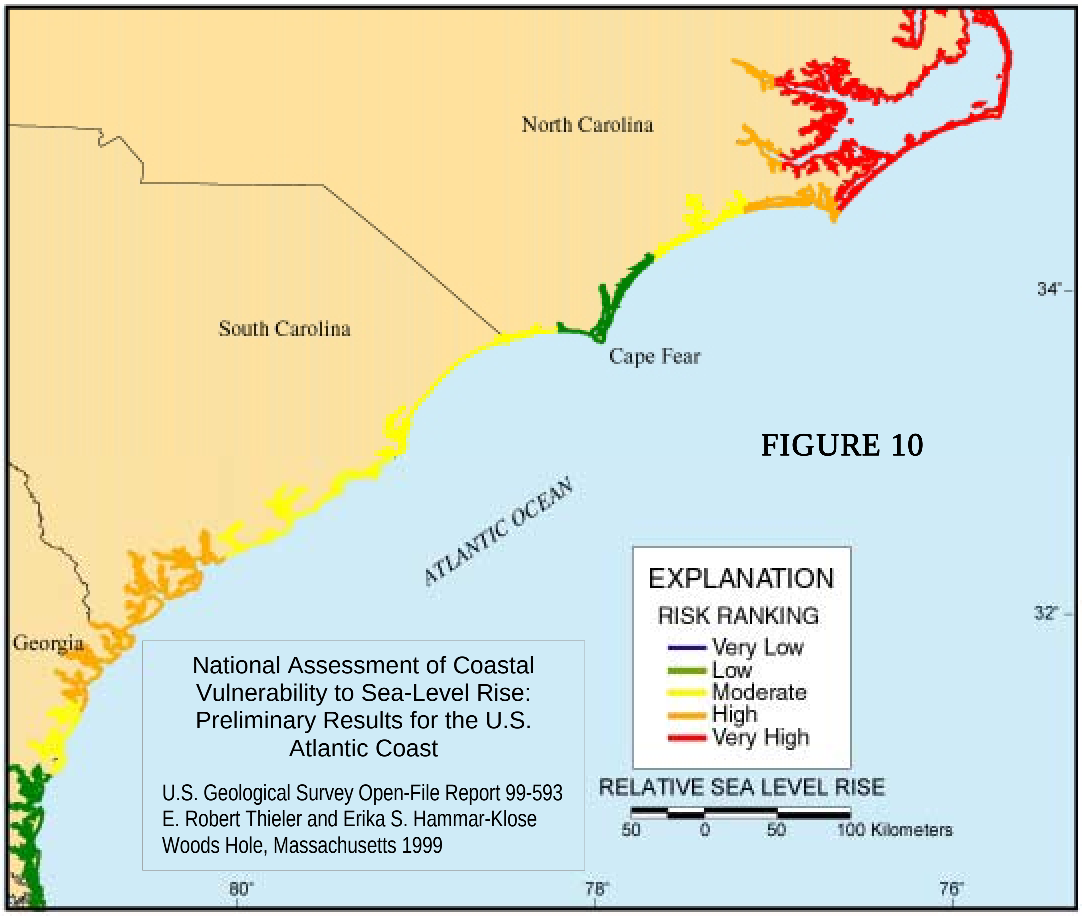


FIGURE 10

Because the weighting process is based upon semi-quantitative data, the incorporation of specific attributes is largely subjective, and quantitative limits for determining absolute parameters such as dune height, beach width and vegetative density must be determined individually for each structure or community.

A Hazard Profile and Vulnerability Matrix can be developed for a street, neighborhood and possibly even an entire barrier island, depending on the objectives of the project. It is important to point out that different Hazard Profiles and Vulnerability

Matrices must be created for different coastal settings, and the results of a vulnerability assessment in one setting will be different, and therefore cannot be compared, to those obtained in another setting

CHAPTER 5: Coastal Hazard Mitigation

No locality on a barrier island is truly safe. Hurricanes, floods, wind, waves, erosion and inlets can all attack any part of an island. In addition, human activity always reduces the relative stability of the natural environment. Human-built structures are static, and when placed in a dynamic system, they tend to disrupt the balance of that system. Interference with sand supply, the disruption of vegetative cover, topographic alterations and other effects of structures can actually create conditions that increase the vulnerability of a structure.

The high density of population and expensive infrastructure of developed communities makes them more susceptible to the impacts of natural events. Therefore, mitigation measures are more critically needed and more amenable to economic justification in developed areas than in less-developed areas. In addition, urban areas are more likely to have, or are able to establish, the institutional arrangements necessary for mitigating hazards. For small communities, non-structural mitigation measures may be the only affordable alternative.

> Apart from the loss of life and the property damages suffered by individuals, the most striking aspect of the storm's effects on Brunswick County shores was the absolute totality of the damage and its implications with respect to storm damages under conditions of dense development. In this connection, there was hardly a vestige of human habitation on the Brunswick County shore following the storm…In view of the severity of tides and waves attendant with Hurricane Hazel, it is reasonably certain that, had development been complete in the area, it would also have been totally destroyed.
>
> **-- US Army Corps of Engineers Report on Coastal High Hazard Zones, 1975**

The work of PSDS is focused upon helping coastal counties and communities identify hazards and reduce their vulnerability to these hazards.

The methodology employed by PSDS involves geologic and environmental principles, decision theory, systems analysis and observational inferences and takes a "process-oriented-perspective" towards hazard mitigation. In so doing, PSDS links the quality of human life to environmental quality.

In a general sense, this effort may be considered "environmental planning" because it consists of diagnosing the needs of a community and identifying the resources available to it, then using this information to formulate a hazard mitigation strategy that integrates many aspects of the community's natural environment.

Accepting Change

Before a barrier island, or any coastal, community, can develop an effective hazard mitigation plan, it must acknowledge, understand and embrace one fundamental rule: that change, the only constant within the dynamic coastal environment, is both inevitable and unpredictable.

While inland communities may be subject to periodic storms of such magnitude and duration as to warrant caution and preparation; tides, waves, inlets, currents, beaches and dunes are in a relentless state of flux along our barrier islands and, as a result, are constantly changing the composition, structure, character and stability of the communities situated on them.

The coastal community courageous enough to acknowledge, plan for and adapt to the changes that lie ahead will put itself in a position to coexist in harmony with nature. The community that chooses to ignore, rather than accept, change will ultimately be relegated to fighting a futile battle against, the forces of nature.

The Basics of Hazard Mitigation

While the preferred mitigation option is to avoid hazards and the most vulnerable locations, this option is not widely achievable in North Carolina where many coastal communities have already reached, or will soon reach, full development potential. Therefore, to effectively mitigate coastal hazards in North Carolina, specific actions must be incorporated into the various stages of the integrated hazard mitigation planning process.

This means that initial preservation of natural environments, better recognition of coastal processes, conservation of sand and vegetation, recognition of the impact of historical storms, post-storm redesign of compatible development, augmentation and "repair" of coastal environments to enhance or restore protective capabilities of the natural setting and public education all need to be the basis for an aggressive and effective mitigation strategy.

Mitigation and the Environment

When identifying hazards and assessing vulnerability in a barrier island community, the environment - the structure and function of the ecosystems that surround and support human life - represents the conceptual framework.

An ecosystem is a coherent set of interlocking relationships between and among living things and their environments. In the context of economic development, the environment is that composite of goods, services and constraints offered by surrounding ecosystems.

A barrier island beach, for example, is a natural ecosystem that provides no material benefits except for panoramic views. The beach, however, provides storm protection, wildlife habitat and recreation. The beach, like any physical resource, also has its constraints. It is dynamic, subject to storms, waves and storm surge and is vulnerable to short and long term erosion. These vulnerabilities, or naturally hazardous processes, constrain the development potential of the ecosystem.

Economic development projects, if they are to be sustainable, must incorporate sound environmental management. By definition, this means that they must be designed to improve the quality of life and to protect or restore environmental quality at the same time and must also ensure that resources will not be degraded and that the threat of natural hazards will not be exacerbated. In short, good natural hazard management is good development project management.

In high-risk areas, sustainable development is only possible to the degree that development planning decisions, in both the public and private sectors, address the destructive potential of natural hazards. This approach is particularly relevant in post-disaster situations when tremendous pressures are brought to bear on local, state and national agencies to replace - frequently on the same site - destroyed facilities. It is at such times that the pressing need for natural hazard and risk assessment information, and its incorporation into the development planning process, becomes most evident.

The Nature of the Planning Area

The physical characteristics of the land, land-use patterns, susceptibility to particular hazards, income level, and cultural characteristics are all considerations when developing a local hazard mitigation plan.

A survey of environmental constraints, whether they are part of an ocean, estuarine, maritime forest or inlet ecosystem, should include:

1. the nature and severity of resource degradation;
2. the underlying causes of the degradation, such as the impacts of both natural phenomena and human use; and
3. the range of feasible economic, social, institutional, policy and financial interventions designed to alleviate degradation. In this sense, natural hazards must be considered an integral aspect of the development planning process.

The Hazard Mitigation Plan

Ideally, a hazard mitigation plan promotes an awareness of the issues related to coastal development, evaluates the threats of natural hazards, identifies the additional information needed for a definitive evaluation and recommends appropriate means of obtaining it.

The first step in developing a hazard mitigation plan is an assessment of the presence and effect of natural hazards in the planning area. The second step involves an estimate of the potential impact of natural processes on development. The third, and final, step includes measures that reduce vulnerability in the plan area.

A community-based hazard mitigation plan may include detailed information on possible mitigation alternatives including:

- Recommended geologic-based coastal hazard mitigation alternatives
- How a recommended mitigation alternative will address a local hazard
- The environmental impacts of the mitigation alternative
- The costs associated with implementing the mitigation alternative
- Potential implementation strategies

Special attention should be given to redevelopment strategies including ongoing redevelopment associated with continuing economic and community development and the periodic window of redevelopment opportunity associated with recovery from a disaster event. At the individual project level, responsibility for mitigating the impacts of natural hazards should not lie with a single individual or governmental component, but should include the cooperation of many.

Post-disaster reconstruction activities often lack support for a hazard assessment intended to characterize potential hazardous events and ensure that the impact of the next event is less destructive. Reconstruction projects, especially when they are very large, are often managed by newly created implementation agencies. This can result in a drain on the already limited supply of technical personnel from existing agencies and complicates coordination between long-term development and short-term rehabilitation.

Mitigation Planning Participants

Among the "actors" involved in the process of hazard mitigation are local and state planning agencies, emergency management organizations, the scientific and engineering community, technical assistance and support agencies, non-governmental organizations and private-sector players such as business and homeowners.

Because each entity has its own interests and approach, these varied, and sometimes conflicting, viewpoints can add to the constraints of planning and putting into operation a hazard mitigation plan. Having advance knowledge of the difficulties each may present, however, can help the planner deal with them.

Community Planners and State Agencies

Most local planners are unfamiliar with natural hazards information or how to use it for hazard mitigation planning. State agencies similarly have little familiarity with natural hazard information or with the techniques of adapting it for use in planning. Projects for the development of roads, energy, telecommunications or other infrastructure often lack hazard mitigation considerations. State agencies also tend to have little experience in collaborating with each other to identify the interrelationships between projects or to define common information requirements so that beneficial information can be cooperatively collected.

Local Governments

Although local communities are aware of the impacts of natural hazards, they usually have little opportunity to participate in the preparation of large infrastructure and production projects that impinge on them, and even less in setting agendas for natural hazard assessment and vulnerability reduction.

Federal Agencies

On a national level, giving a single entity total responsibility for hazard management tends to cause other agencies to see it as an adversary. Instead, each agency that formulates projects as part of its standard activities should appreciate the importance of introducing hazard considerations into the process of planning. Agencies should, therefore, take an advocacy position on hazard management and on introducing non-structural mitigation strategies early in the planning process. Such agencies should have personnel trained for these functions.

Emergency Management

The emergency preparedness community has historically viewed its role exclusively as preparing for and reacting to emergencies (although this is beginning to change). As a result, this group often fails to link preparedness to long-term mitigation issues. Furthermore, emergency managers often pay insufficient attention to the vulnerability of their own infrastructure.

Scientific And Engineering Community

The scientific and engineering community often sets its agenda for research and monitoring on the basis of its own scientific interests without giving due consideration to the needs of vulnerability reduction or emergency preparedness. For example, valuable information on hazards is often published in scientific journals in abstruse language. The scientific community should ensure that data is translated into a form suitable for use by hazard management practitioners.

Disaster Management Agencies

Most disaster support organizations engage actively in post-disaster reconstruction measures, but do not insist on hazard assessment, mitigation, and vulnerability reduction measures, and are often reluctant to incorporate such considerations into their ordinary (non-disaster-related) activities.

Technical Cooperation Agencies

Knowledge of and experience with hazard management techniques are rare commodities in most state and local agencies. Thus, if a technical cooperation agency such as a research university proposes to incorporate ideas into planning and project formulation, it invariably has to overcome the skepticism of the relevant local personnel. This adds to the cost of formulating a project, but the extra cost can pay high dividends.

Private Sector

Greater consideration should also be given to the private sector. Claims have been made that policy-makers can change social behavior more effectively by changing the incentives of the marketplace, i.e., the public use of private interest, than by regulation. For example, casualty insurance companies could offer a large premium differential for hurricane-resistant construction. A government agency could specify the desired outcome of a policy, but leave the method of achieving that outcome to the economic actors.

CHAPTER 6: PSDS Coastal Hazard Mitigation Alternatives

PSDS has developed a comprehensive catalog of geologic-based, non-structural coastal hazard mitigation alternatives that may be used in both developed and developing barrier island communities. This section provides an overview of each mitigation alternative including:

1. qualitative causal relationships with storm processes (how the mitigation alternative may reduce or enhance a given storm process),
2. potential environmental impacts (whether the mitigation alternative will impair or improve environmental quality) and
3. long-term costs (whether the long-term costs of implementation are high or low).

Hard stabilization alternatives such as seawalls, revetments bulkheads and groins are currently illegal in North Carolina and will not be discussed in this report. Temporary erosion protection strategies such as sandbags also will not be included in this report.

Specific recommendations for each community are provided in Chapter 6 which contains individual summaries for each of the five model study communities.

Dunes

Coastal barrier dunes are formed by wave and wind action. In North Carolina, waves bring sand from the inner continental shelf to the shore where it is transported landward by onshore winds. Obstacles such as driftwood, sand fencing or vegetation reduce wind speed, causing sand to accumulate. As sand accumulates, plants adapted to the beach environment emerge, stabilizing the surface and promoting further dune formation. In the absence of stabilizing vegetation, blowing sand may drift into large "live" dunes that move back and forth with the wind, such as Jockey's Ridge near Kill Devil Hills

The Beach-Dune System: Functions, Values and Limitations

Dunes act as flexible barriers to ocean storm surges and waves, protect low-lying backshore areas and help preserve the integrity of low barrier islands. In addition, they provide a habitat for many animals including migratory birds.

Dunes formed as a result of vegetation act as natural sand reservoirs for beach nourishment. During storms, sand that erodes from the beach-dune system is often deposited as shallow offshore sandbars. In a stable beach-dune system, sand that is moved offshore during storms is often returned during calm weather. Thus, the dunes, beach, and near-shore sandbars act as a dynamic, integrated unit which is often referred to as the beach-dune system.

A detailed study of the South Carolina coast after Hurricane Hugo concluded that the minimum dune field that survived Hugo, and thus protected buildings, was 100 feet wide with dunes about 10 feet high. Most of the buildings damaged or destroyed by Hugo were fronted by dune fields less than 50 feet wide (Bush, 1996).

Although dunes serve as temporary protective barriers during storm tides of short duration, they are not effective against persistent beach recession caused by rising sea level, migrating inlets or changing shoreline dynamics. Therefore, they cannot be considered permanent structures that will "hold off the ocean."

The value of dunes and their fragile nature are often misunderstood or not appreciated. Excessive use often upsets the natural balance, damaging the vegetation and deteriorating the dune system. One of the earliest uses of dunes in North Carolina that resulted in considerable damage was overgrazing by cattle, horses and sheep. Today, shoreline development and the pounding of dunes by feet and vehicles pose serious threats to dune vegetation and dune stability.

Intensive beach use increases the need to restore, construct, protect, and manage dunes. With proper planning and management, however, dune functions may be enhanced or restored.

Restoring Dunes

Dune sands are readily moved and shaped by wind and water action. Consequently, disturbed dunes revert rapidly to unstable conditions, regardless of their stage of development at the time of disturbance.

As a result, dune restoration usually begins with the establishment of pioneer plants and vegetation is critical to dune formation and stabilization. Without vegetation, blowing sand will migrate inland.

Dunes that are only slightly damaged may be repaired by planting vegetation in bare areas, giving stressed grasses a judicious amount of fertilizer and protecting the area from trampling and traffic.

Selection of plant species is of paramount importance when restoring vegetation in bare areas of existing dunes. Dune plants must be able to survive sand blasting, sand burial, salt spray, saltwater flooding, heat, drought and a limited nutrient supply. Only a few plant species can tolerate these stresses.

Dune Grasses

Perennial grasses are the primary stabilizers of frontal dune systems along the North Carolina coast which is in a transition zone between the northern-dominant American beachgrass and the southern-dominant sea oats. Bitter panicum or "running beachgrass" is also an important grass on frontal dunes in North Carolina.

American Beachgrass

American beachgrass is a cool-season dune grass native to the North, Mid-Atlantic, and Great Lakes coasts. North Carolina is at the southern end of its natural range. American beachgrass is a vigorous, upright grass that grows in dense clumps and is capable of rapid lateral spread by runners. Hence, it is widely used for initial stilling of blowing sand. It is easily recognizable by its dense, cylindrical spikes or seed heads.

Several characteristics make American beachgrass suitable for dune building and stabilization in North Carolina:

- Quick establishment and effective trapping of sand the first growing season.
- Ease of harvest, storage, and transplanting, with an excellent survival rate.
- Commercial availability from nurseries at a low cost.

Recommended cultivars include Hatteras, Bogue, and Cape. Hatteras is a fine-leaf type that produces good results in the Carolinas. Bogue is another selection being used in the state. Cape, a northern strain that declines rapidly after the first growing season, is not recommended. Hatteras and Bogue are both available from commercial producers.

Because American beachgrass is a cool-season grass, the best planting dates are November through March. Plant small areas by hand using a dibble to open a hole 1 inch in diameter and 8 to 10 inches deep. Pack sand firmly around the plants after they are placed in the holes. Space the plants 18 to 24 inches apart at the crest of the dune and increase the spacing to 2 feet and then to 3 feet for several rows on each side of the crest.

After establishment, American beachgrass will grow through as much as 4 feet of sand accumulation during one growing season. Although it grows quickly where sand accumulates on the seaward dune edge, it tends to die out behind the dune crest after only a few years. This die-out is caused by climatic effects, fungal disease, and insects.

To further increase the diversity and stability of the beach-dune system, sea oats and bitter panicum should be included in beachgrass plantings.

Sea Oats

Sea oats are a warm-season grass, native to coastal dunes from the Virginia Capes to Mexico. The plant's striking appearance, especially in bloom or fruiting, has made legal protection necessary in some areas to avoid excessive harvest. Due to an extensive root system, sea oats persist both seaward of the dune and behind the dune crest. Other characteristics include:

- Vigor and drought tolerance.
- Effective trapping of sand.
- Low incidence of pests.
- Excellent persistence.
- Tolerance to a limited supply of nutrients.

Planting stock may be acquired as seedlings from commercial producers, or, with permission on private property, transplants can be dug from existing stands. The best transplants are 1- to 3-year-old seedlings often found in small clusters seaward of the frontal dune.

Although sea oats provide the best long-term stability, the grass does not spread as rapidly as American beachgrass, and its slow lateral spread results in steep dune slopes. It should be planted in conjunction with American beachgrass or bitter panicum because of their more rapid spread and lower cost per plant. Planting methods and spacing for sea oats are similar to those described for American beachgrass. Because sea oats are a warm-season grass, the best planting dates are March through June.

Bitter panicum

Bitter panicum or "running beachgrass" is a warm- season grass found on dunes from New England to Mexico. It is useful for inclusion in American beachgrass and sea oats plantings to increase plant diversity. A wide variety of species is available, with variable stem sizes and growth characteristics. Although bitter panicum grows and multiplies relatively well in field nurseries, it is not as widely available as American beachgrass. Commercial availability is limited, and plants may have to be obtained by thinning local stands. Bitter panicum will root at each node on the stem, so it may be planted by placing runners in a trench 6 to 8 inches deep and covering the runners with sand. Leave one third of the upper shoot out of the ground. The best transplanting dates are March through May.

saltmeadow cordgrass

A fourth grass, saltmeadow cordgrass, although not a true dune grass, often traps sand to initiate dune growth. Saltmeadow cordgrass grows well in low, moist areas such as sand flats and high salt marshes and is more salt- and flood-tolerant than the dune grasses. Saltmeadow cordgrass is useful for planting in low areas subject to occasional saltwater flooding during storms. Its range includes all of the Atlantic and Gulf coasts of the United States. Saltmeadow cordgrass often initiates new dunes on low flats that may later become occupied by plants better adapted to dry conditions.

Seedlings are commercially available from wet- land plant nurseries. Plants can also be obtained by digging from young open stands where plants are vigorous. Planting methods and spacing are similar to those described for American beachgrass. The best planting dates are March through May.

Planting a combination of several of these species can enhance the beach-dune system's diversity and long term viability.

Seashore Elder

Seashore elder, a low-growing woody shrub, also grows well on frontal dunes and may be transplanted to add diversity to the dune system. Seashore elder spreads both by seed and vegetatively as roots develop on stems buried by sand. It adds diversity to the landscape and is useful for planting where American beachgrass has died out.

Plants can be obtained by collecting and rooting the cuttings, or rooted stems may be dug from around existing plants. Seedlings are often found around older plants and in drift lines. Planting in early spring is usually the most successful.

Dune Construction/Repair

When barrier dunes are absent, or where dune gaps are present, they may be rebuilt or plugged by bulldozing, dredging or by trapping blowing sand with sand fences and vegetation. Building dunes with vegetation is more economical than using heavy equipment and discourages placement of the dune too close to the ocean or in other unsuitable locations.

Man-made dunes should be of the same general height, slope, width, and shape as the natural dunes in the vicinity. Generally, they should be no less than 4 feet high with a slope of no more than 45 degrees (a rise of 1 foot for every 1 horizontal foot). A slope of about 18.5 degrees (a rise of 1 foot for every 3 horizontal feet) is preferred. The initial width of the dune base should be at least 20 feet. A dune with a smaller base will not build to a height sufficient to provide storm protection (Texas GLO, 2001)

Barrier dunes are best located slightly landward of the location where foredunes would naturally occur to allow for natural seaward expansion and normal ocean tidal fluctuations. Dunes built too close to the ocean can be destroyed by wave action during even minor storms and may interfere with public access along the beach.

As the dune accumulates sand it expands seaward, allowing plants to spread into freshly deposited sand. Some severely eroding beaches do not have sufficient space to successfully use vegetation for dune building. Where adequate distances exist between the ocean and property to be protected, well-vegetated dunes will provide valuable protection from storm waves.

Imported sand should be similar in size and mineral content to the sand at the dune-building site. If native sand is topped with imported finer sediment, the finer sediment will quickly erode.

Bulldozing

Beach Bulldozing (or scraping) is a process in which a thin layer of beach sediment (one foot or less) is moved from the high tide line in an effort to reconstruct or repair frontal and/or primary dune systems. Bulldozing is expensive, potentially damaging to the coastal environment, results in short-term benefits and needs to be perpetually continued.

Sand Fences and Vegetation

The first step to dune establishment is providing a barrier to trap sand. Sand fences create areas of lower wind speed both in front of and behind the fence which encourages sand deposition. The amount of sand trapped depends on the fence height, the size of spaces between fence slats and the wind speed. Wooden slat fences are most commonly used and are generally preferable to fabric fences.

The initial dune crest is located by installing a 2-foot-high sand fence several hundred feet behind and parallel to the high tide line to accumulate wind-blown sand. The fence should be installed several months before transplanting vegetation to allow the sand to accumulate without burying the transplants. Sand fences should be avoided in areas where sea turtles are likely to nest.

Small areas and steep slopes should be planted by hand, while large, flat areas may be planted with tractor-drawn tobacco or vegetable transplanters that have extended planting shoes. Furrows should be 8 to 10 inches deep and spaced at least 18 inches apart. Plants should be closely spaced, 18 inches by 18 inches, in several rows where the crest of the dune is to be located. Spacing should then be increased to 2 feet and then 3 feet for several rows on each side to allow sand to penetrate to the center of the planting.

Dune Protection

Although dune plants tolerate harsh beach conditions, they cannot withstand foot and vehicular traffic. These activities crush plant shoots and roots, and trampling by pedestrians and traffic such as four- wheel-drive vehicles and trail bikes often lead to greater sand removal by wind. In addition, soil compaction often results from vehicular traffic and decreases water infiltration, leading to erosion from rain and increased damage during droughts.

Restricting or banning access to dunes can reduce the need for other sand control measures. However, some dunes will have to bear traffic, and to protect them, crosswalks and beach access areas should be designated.

Dune Crossovers

Damage to dunes from pedestrian traffic can be avoided by the use of elevated walkovers for access to the beach. If walkovers are conveniently placed near access roads, parking areas, beachfront subdivisions, and public facilities pedestrians will be less likely to cut footpaths through the dunes. Also, providing walkovers may increase public awareness of the importance of dunes and promote an appreciation of the sensitivity of the dune environment.

A walkover should begin landward of the foredune and extend 10 to 15 feet seaward of the vegetation line. The structure should be oriented at an angle to the prevailing wind direction. Otherwise, wind blowing directly up the path of the walkover may impede the growth of vegetation beneath it, erode sand from the seaward end and increase the possibility of washout or blowout development (Texas GLO, 2001).

Wood is the preferred construction material for walkovers because it is less expensive than metal, does not collect and retain heat as metal does, and is readily adapted to a number of designs. Treated lumber and galvanized nuts and bolts should be used.

The width of a walkover should be based on the expected volume of pedestrian traffic. If a walkover will be infrequently used, a width of 2 feet should be sufficient. Walkovers intended for two-way passage should be wider, perhaps 3 or 4 feet. A width of 6 feet may be appropriate for a walkover subject to heavy use.

The structure's height should be at least one to one and a half times its width to allow sunlight to reach vegetation underneath. In any case, the deck of the walkover must be of sufficient elevation to accommodate the expected increase in dune height.

The slats forming the deck of the walkover should be spaced 1/2 inch apart so that sunlight and rainfall can penetrate to plants below and so that sand will not accumulate on the deck.

Supporting piers should be placed as far apart as possible along the length of the structure (a distance of at least 6 feet between pairs of piers is recommended). Piers should be implanted at least 3 feet in the ground to ensure stability, although a depth of 5 feet or more is advisable to allow for erosion around the piers during storms. Damage to the dune area should be repaired as soon as possible.

Providing handrails on both sides of the walkover is recommended as a safety measure and to discourage people from jumping off into the dunes. Railings are particularly advisable on public walkovers and those that are high above the ground. Railings should be at least 3 feet high.
To enable handicapped people to use a walkover, inclined ramps with a 20-percent slope (a 1-foot rise for every 5 feet in length) may be built at each end of the structure. Ramps are recommended for any large public walkover.

Walkovers should be inspected and promptly repaired. To avoid damage, workers should enter the dune area on foot rather than by vehicle.

Enhancing Interior Dunes

Dunes found on island interiors serve an important function with respect to property damage mitigation. Dunes provide elevation and protection from storm-surge flooding and waves. Their height can also act as a shield against damaging wind. The removal of interior dunes eliminates the potential mitigation benefits they would have provided and allows storm impacts to become magnified.

Unlike frontal dunes, once an interior sand dune is destroyed, it can only be rebuilt or repaired artificially by adding sand to the system. This can be done independently, or during a beach nourishment project when sand-pumping equipment is readily available. A hypothetical interior sand dune 30 feet wide at its base, 10 feet wide at the top, 10 feet high and 200 feet long would have a volume of 1,500 yds^3. The estimated cost of constructing such a dune in South Carolina is approximately $7,500.00 (Bush, 1996).

Beaches

One of the primary roles of the open ocean beach is to absorb and dissipate storm energy. As a result, the beach serves as an effective natural buffer between an island's interior and storm=related processes such as surge and waves.

In addition to serving as a storm buffer, beaches also provide habitat and act as sediment sources for the remainder of the island. In the absence of human impacts or influence, a natural beach will always remain in a state of equilibrium with its natural surroundings.

In the same way that a beach reduces storm impacts upon an island, the beach also acts as a buffer between storms and human development. While a wide beach affords a degree of protection for human development, it does not mean that all beaches should be artificially altered and maintained for human benefit.

When the open ocean beach is artificially managed or altered, two seemingly incompatible elements must be considered - a naturally dynamic and highly unpredictable environment and static human economic development. Conflicts only arise when naturally-occurring coastal events and processes begin to impact upon human economic development.

For example, a major storm might remove sand from the sub aerial portion of the beach including any frontal or primary dunes. From a human perspective, this is considered storm damage. From a geologic perspective, however, this is considered normal - the beach is simply doing what it has been doing for millions of years.

Along developed shorelines, situations like this often lead to questions such as, "What, if anything, should be done to the beach?" As more and more human economic development becomes vulnerable to coastal processes, the pressure to do "something" is becoming greater every day.

What, if anything, a community does to manage its ocean beach for the benefit of human economic development depends upon a number of complex local, regional, state and federal factors. Whatever strategy is eventually chosen, one element in the decision-making process is absolutely essential: all facts must be made public, discussed and debated in an open forum.

Some management alternatives that address the conflict between static human economic development and the naturally dynamic ocean beach in North Carolina include:

Beach Nourishment

Beach nourishment (or beach replenishment) is a beach stabilization technique used to restore an eroding beach and create a new sandy shoreline. Beach nourishment involves the placement of sand fill with or without supporting structures along the shoreline to widen the beach. Sand sources include the continental shelf, inlets and associated tidal deltas, lagoons and inland sand pits.

The first documented beach nourishment project in the United States took place at Coney Island, NY in 1922-23. Between 1950 and 1996, the federal government spent $1.64 billion on shore protection and beach erosion control projects. Since 1996, Congress has authorized over 40 beach replacement projects that will cost more than $3.38 billion (TCS, 2001).

Although nourishment can be a viable engineering alternative for shore protection and is the principle technique for beach restoration, there are a number of significant issues surrounding the use of beach nourishment as a hazard mitigation alternative. In addition to being expensive, nourishment is not suitable for all locations - especially those with high erosion rates.

Beach nourishment projects are often undertaken without due consideration for the environment, without due consideration for their impacts upon the littoral cell, without due consideration for their impacts to the borrow site and without an effective monitoring component. The adequacy of beach nourishment design methodology is also a source of controversy.

In addition, most nourished beaches tend to erode faster than the natural beaches that preceded them because the “new” beach is just piled on top of the upper beach, resulting in a beach that is steeper and out of equilibrium with the local wave climate (Bush, 1996).

And, like hard shore protection structures, beach nourishment has a finite life which depends on the intensity of the destructive forces of nature and, occasionally, of human activity (NRC, 1995).

If a community does decide to pursue beach nourishment as a property damage mitigation measure, it must understand that nourishment is a temporary (50-year) solution that does nothing to address the underlying problem of a rising sea level and a migrating shoreline. It must also realize that nourishment is very expensive, highly unpredictable and that it does not provide any environmental benefits.

Every community that pursues beach nourishment should ensure that development densities do not increase because of nourishment and should develop a long-term, post-nourishment mitigation plan that incorporates structural relocation.

Beach Scraping

Beach scraping consists of moving sand from the low-tide beach to the upper back beach (independent of building dunes). During beach scraping, a thin (1 foot) layer of sand is removed from over the entire lower beach using a variety of heavy machinery and spread over the upper beach. The objectives are to build a wider, higher high-tide dry beach; to fill in any trough-like lows that drain across the beach and to encourage additional sand to accrete on the lower beach. Any newly accreted sand can, in turn, be scraped, leading to a net gain of sand on the manicured beach. The goal of an enhanced recreational beach is achieved for the short-term but the drawback is that no new sand is added to the system.

Ideally, scraping is intended to encourage onshore transport of sand, but most of the sand “trapped” on the lower beach is brought in by the longshore transport. Removal of this lower-beach sand deprives downdrift beaches of their natural nourishment.

Beach scraping is widely applied in many states, and although a beach’s width may become slightly enhanced over the short-term, its effectiveness is relatively unproven. The general view on beach scraping is that it should be treated as highly experimental, and that any community contemplating it should consider it as such.

Vegetation

Preserving/ and Establishing Native Vegetation

Natural coastal vegetation, where it has not been disturbed, offers some of the best defense against property damage during storms. For moderate-sized storms, dense maritime forest, especially native species of forest, provides significant protection to buildings.

Maritime Forest

On higher elevations where the substrates are unaffected by salt water flooding and heavy salt spray, maritime forest may occur. The forest is the climax of the successional process and is the stage that follows the shrub thicket. The maritime forest is composed of tree species such as live oak, loblolly pine, red bay, red cedar and American holly that are relatively resistant to salt spray.

The protective nature of maritime forest is clearly illustrated by the impacts of Hurricanes Hugo in 1989 and Frederic in 1979. In Hugo, overwash penetration and storm wave damage to property on Pawley’s Island, SC was noticeably greater where maritime forest had been removed for development. In contrast, many houses located with the maritime forest were essentially untouched except for some cosmetic damage. On Dauphin Island, AL the unforested western segment of the island suffered extensive damage while the forested eastern segment suffered less damage. This pattern of damage on the island was repeated in later storm events (Bush, 1996).

Every measure should be taken to protect and preserve contiguous areas of shrub thicket and maritime forest. Not only should as much forest as possible be retained, but also, where appropriate, areas where trees have been removed should be reforested with native species.

One approach is to restrict the removal of trees that have a trunk diameter less than a defined standard, such as 2”. Another option is to control development density so that as much natural (or forested) land is preserved.

Innovative Development Policies

The mitigation alternatives discussed up to this point involved direct or indirect manipulation of coastal resources as a means to alter the vulnerability of human coastal development. The remainder of this chapter examines approaches that address vulnerability through the implementation of innovative concepts and policies that directly and indirectly involve the specific attributes of human coastal development.

Structural Relocation

The most obvious type of relocation is to physically pick up a building and move it somewhere else, either in one piece or in sections. Relocation can also mean demolishing and rebuilding somewhere else. Any active (before damage) or passive (after damage) method of moving, or abandoning and rebuilding, is essentially what is meant by relocation.

Abandonment may also be an economically sound option, especially when a building has existed well beyond its design life and where the cost of moving, or protecting the building in place, exceeds the building’s value.

The advantages of relocation are preservation of the beach, preservation of buildings and reduced shoreline stabilization costs. The major drawbacks are that relocation can be politically difficult, costly and land will ultimately be lost.

When a building is threatened by erosion, the costs and benefits of moving the structure back from the shore must be weighed along with other alternatives such as shoreline stabilization. Depending on the nature of the problem, a move-back can compare favorably to other alternatives and prove to be economically and aesthetically superior in the long run.

Relocation has been employed on the coast for almost 150 years, and a 1987 amendment to the National Flood Insurance Program formally recognized relocation as a more economical, permanent and realistic way of dealing with long-term erosion problems. Known as the Upton-Jones Amendment, this statute allowed owners of imminently threatened structures to use up to 40 percent of the federally insured value of the structure for relocation or demolition purposes (Bush, 1996).

The goal of the amendment was for the federal government to pay a relatively small amount of money to help move a structure, rather than pay a much larger sum after the structure has sustained damage. By March, 1995 North Carolina had claims for over 70 relocations and 168 demolitions which accounted for over 60% of all coastal claims under the amendment.

The National Flood Insurance Reform Act of 1994 terminated the relocation assistance program and replaced it with the National Flood Mitigation Fund which would be financed by revenue collected for noncompliance with National Flood Insurance Program (NFIP) requirements. The Fund provided state and local governments with grants for planning and mitigation assistance for activities that will reduce the risk of flood damage to structures covered under the NFIP.

Although demolition and relocation activities were still eligible for funding, they had to compete with other mitigation approaches such as acquisition, flood-proofing programs and beach nourishment.

The 10/100-Year Relocation Concept

In some areas, such as Miami Beach and Myrtle Beach, SC, beach nourishment may be economically feasible because of the large number of people that use the beach and the enormous amount of revenue generated. There will come a time, however, when the economics of nourishment are no longer favorable, even in these highly-developed communities.

What do we do then? One possible answer is relocation or demolition. According to the International Association of Structural Movers, even large structures such as high-rise hotels and multi-unit condominiums can be safely moved. The only obstacles that must be overcome are cost and opposition from beachfront property owners.

One option available to all communities - large and small, developed and developing - is to develop a 10/100-year relocation plan. This plan would contain a relocation strategy developed over a 10-year period and implemented, as needed, over the next century (Bush, 1996). Cost comparisons of traditional relocation or relocation by demolition could be considered and potential relocation sites identified. The goal is to plan now so that proper questions can be identified and addressed before they become problems.

Staggered Shoreline Setbacks

Setbacks allow the natural erosion and accretion cycles to occur and help maintain lateral beach access. Setbacks also provide open space for the enjoyment of the natural shoreline environment. The intent of staggered shoreline setbacks is to establish a variable buffer zone that protects beach-front development from high-wave events and coastal erosion

It is the opinion of PSDS that existing NC shoreline setbacks are inadequate because they do not consider acute storm impacts and other geologic hazards. Along much of the North Carolina coastline, setbacks have failed to protect developed beach-front property from coastal erosion and storm impacts, and have failed to provide adequate environmental open space for coastal processes.

An analysis of coastal erosion trends could provide data on a property scale to enhance decision making in the coastal zone area. Historical erosion rates can be determined on a parcel by parcel scale and used to project the future erosion hazard area along the shoreline. Maps projecting the 30-, 60-, and 90-year shoreline position, and that incorporate other hazard geoindicators, can be developed.

These maps would provide a scientific basis for more effectively locating proposed structures and activities in beachfront lots. Coastal hazard maps could also be used to establish hazard-based building setbacks. Setbacks would be site-specific, at the property scale, to reflect the site-specific nature of coastal hazards. These setbacks would also incorporate the proposed style of development.

Construction-style considerations would include the size and expected lifetime of the planned structure. Larger, immovable buildings and those with lifetimes of more than 60 years, for example, would have deeper setbacks than small, movable structures. For instance, a ten-story, 200-unit condominium would have a deeper setback than a single-family house built on posts.

Establishing setbacks that reflect site-specific coastal processes, hazards and building styles could be incorporated directly into a community's Land Use Plan along with certain construction and land-use performance standards for areas that fall within a particular erosion-hazard zone. Site-specific setbacks would also offer a basis for dune conservation.

Variable-rate setbacks may be difficult to adopt, however, especially in communities where rapidly eroding shorelines could significantly limit the buildable area of many beach-front parcels.

Staggered setbacks prevent entire rows of structures from being lost in a single storm (as was the case in Oak Island, NC during Hurricane Floyd), thereby minimizing the severe financial impacts that even a moderate hurricane may have on a community

Orientation and Placement of Roads and Infrastructure

Most structural mitigation measures concerning development deal with engineering and/or building codes. Other measures, such as those that mitigate damage to utilities and other infrastructure, have to do primarily with orientation, placement, layout and design.

Based on the damage patterns observed after Hurricanes Gilbert and Hugo, it has become clear that road orientation, design and placement can influence storm processes and is a major factor contributing to property damage. During Hugo, for example, water, sand and debris were carried inland along shore-perpendicular roads in several communities. On one South Carolina island, boat ramps served as conduits for the return of storm water (storm-surge ebb) back across the island from the lagoon, causing scour channels that undermined roads and damaged homes.

Some of the problems associated with standard road layout designs and practices, however, can be remedied, or at least alleviated, through the implementation of innovative mitigation alternatives. It should be noted that because development is dependent upon infrastructure, and because infrastructure encourages additional development, all coastal communities should implement the following two-part strategy: 1) permanently move infrastructure in the most vulnerable locations, and 2) prohibit future infrastructure from being located in these locations.

Not only would this reduce the amount of development in high-hazard areas, it would also support the goals of the Coastal Barrier Resources Act of 1982. The CBRA eliminated federal development incentives on undeveloped coastal barriers with the intent of preventing the loss of human life and property from storms, minimizing federal expenditures and protecting habitat for fish and wildlife.

In those areas where infrastructure is located, the following mitigation strategies may be used.

Road Realignment

If the direct line created by straight roads perpendicular to the shore can be interrupted, the amount of damage done by overwash and storm-surge flood and ebb waters may be reduced.

The first hazards that should be addressed are dune gaps located at the ends of shore-perpendicular roads. These gaps should be plugged, or at least partially filled to slow down storm-surge ebb velocity enough to reduce the scouring potential of the flow and reduce or delay the intrusion of storm waves into the community.

Adding a few simple curves, instead of having all access roads run perpendicular to the shore, would greatly reduce the impact of overwash and storm surge ebb. Existing roads could either be removed and rebuilt, or curved to interrupt the existing grid pattern, in order to eliminate the conduit effect. New roads could simply be laid out in a non-linear, non-perpendicular manner.

Another option is the placement of sediment mounds - artificially-created, T-shaped sand dunes - at specific street intersections and at the end of finger canals. Sediment mounds can be designed to function as parks (albeit small ones) or used for aesthetic plantings, and would cost approximately $10,000 apiece.

Road Elevation

Many coastal communities have roads at dangerously low elevations, making them vulnerable to overwash, undermining and flooding. While some communities would be better off prohibiting any new construction along these roads, other communities can benefit by elevating sections of roads, thereby allowing natural processes to continue with minimal impacts.

Road elevation design must pay careful attention to natural processes so as not to interfere with natural drainage or sediment transport. When roads are located or rebuilt/relocated after storms, for example, they should be elevated above the initial flood level of a storm in order to allow for evacuation. This additional elevation may also offer protection against storm-surge currents.

There are two possible approaches for elevating a road. The first is to construct a bridge, causeway or other structure that physically raises and maintains the road at a constant height above the ground surface. A second alternative is to construct “temporary” roads that are “sacrificed” during storms and that can be quickly rebuilt, post-storm, on top of any sediment that gets deposited. This option allows an island’s elevation to build-up naturally, and may prove to be both inexpensive and environmentally-sound.

Inlet Hazard Area Restrictions

Land near inlets is subject to inlet migration, rapid and severe changes in watercourses, flooding and strong tides. Because of their dynamic nature, North Carolina has designated land adjacent to inlets as hazard areas and areas of environmental concern.

The NC Inlet Hazard Area extends landward from the mean low water line a distance sufficient to encompass that area within which the inlet will, based on statistical analysis, migrate, and shall consider such factors as previous inlet territory, structurally weak areas near the inlet and external influences such as jetties and channelization (CAMA, 1974).

Although our understanding of the complexity of inlets, their dynamics and their importance to barrier island processes has grown significantly since the North Carolina Coastal Resources Commission designated the current inlet hazard areas in 1978, use standards and boundary line determinations have remained static (CAMA, 1974).

We now know that inlets are not fixed features, that each inlet is unique and that they all require a special consideration in applying principles of property damage mitigation because a special set of natural processes are at work. Inlet hazard mitigation measures include land-use planning and zoning ordinances that require an intimate understanding of coastal processes in order to delineate the most hazardous areas and avoid potential hazards.

Defining Inlet Hazard Areas

Inlet Hazard Areas currently fail to account for the significant, and often rapid, shoreline changes that can be caused by major storm events. In addition, Inlet Hazard Areas also do not include land that may be influenced some distance away from the inlet.

To address these issues, a community should consider expanding the boundaries of the Inlet Hazard Area within its jurisdictional boundaries in order to encompass all areas that are, or may be, impacted or influenced by inlet processes. This task can be accomplished by evaluating post-storm shoreline changes and by examining aerial photographs.

Inlet Hazard Areas also only pertain to modern inlets and do not consider relict or historical inlet locations. A community should determine whether any historic or relict inlets are present and designate those areas as hazardous areas as well. These geologic features can be identified through a literature search as well as through an evaluation of aerial photos.

Use Standards in Inlet Hazard Areas

In addition to establishing new inlet hazard area boundaries, use standards within these areas may be revised. This could include the application of current CAMA Inlet Hazard Areas Use Standards to the newly delineated areas, or the development of more restrictive use standards.

Enforce Building Codes

Good code enforcement can make a significant difference in the losses incurred by a storm event, especially related to mobile homes. There is a strong correlation between good code enforcement, new construction that complies with NFIP regulations for elevation and construction and reduced flood and wind damages. Structures built before NFIP regulations were strictly enforced in South Carolina in the early 1990s suffered severe flood damages during Hurricane Hugo.

The North Carolina State Building Code is an adaptation of the Standard Building Code that incorporates significant changes made by the North Carolina Building Code Council. Since the 1960s, North Carolina has had a special building code for one- and two-family dwellings, called the Residential Building Code, which is based on the Council of American Building Officials Code with amendments from the North Carolina Building Code Council.

Since the 1960s, most houses on the North Carolina coast have been built on pilings. Before 1986, codes required pilings to be embedded 8 feet below grade. In 1986, the code was revised so that buildings closer than

60 times the long-term erosion rate to the seaward edge of the first line of stable vegetation must have pilings embedded 5 feet below mean sea level or 16 feet below grade, whichever is less.

Since 1997, a strengthened Residential Code applies to new houses built up to 100 miles inland from the coast. The private sector should work closely with state and local governments to develop incentives, disincentives and revised insurer practices to prevent or mitigate wind, flood and related damages through improved building practices (Pilkey, 1996).

Mobile Home Regulations

Mobile homes differ in both construction and anchorage from “permanent” structures. The design, shape, lightweight construction materials and other characteristics required for mobility also creates a unique set of potential problems for residents of these dwellings. Because of their thinner walls, for example, mobile homes are more vulnerable to wind and windborne projectiles.

Recognizing the effects of coastal zone processes on these structures, North Carolina has a separate building code for mobile homes. The code requires that mobile homes manufactured after October 1, 1973 meet the state’s hurricane-zone requirements. Mobile home anchorage is commonly regulated by local ordinances, and most NC counties and municipalities have ordinances pertaining to mobile homes.

Tie-downs should be, and often are, required to make a mobile home more stable against wind stress. Violations of anchorage or foundation regulations may go undetected unless there are a sufficient number of conscientious inspectors to monitor trailer courts. One poorly anchored mobile home can wreak havoc on adjacent homes whose owners abide by sound construction practices.

Replace Pavement with Porous Surfaces

A simple method that may help reduce scouring is to remove pavement and replace it with rounded pebbles, gravel, sand or some other porous surface. This adds some roughness to the surface and allows water to seep into the ground, rather than flow directly back to the ocean or sound.

Structural Design Considerations

A certain chance of failure exists for any structure built within the constraints of economy and environment. The objective of building design is, therefore, to create a structure that is both economically feasible and functionally reliable.

There are six fundamental considerations that should be incorporated in the design and construction of a coastal structure:

1. A coastal structure exposed to high winds, waves and flooding should be stronger than a similar structure built inland
2. A building with a planned long life, such as a year-round residence, should be stronger than a building with a planned short life such as a mobile home
3. A building with high occupancy, such as an apartment, should be safer than a building with a low occupancy, such as a single-family dwelling
4. A building that houses elderly or sick people should be safer than a building housing able-bodied people
5. Construction costs that incorporate a higher than usual margin of safety will be higher than costs for an average home
6. The risk of loss may make a project unfeasible

Builders commonly assume that the foundation and framing of a structure must support the load of the walls, floor and roof, and relatively insignificant horizontal wind forces. A well-built house in a hurricane-prone area, however, must be constructed to withstand a variety of strong wind and wave forces that may come from any direction.

Designing for Wind

According to the building code, the design wind speed for North Carolina is 110 mph, the fastest mile for a 50-year return frequency. Most wind damage is not caused by uniform horizontal pressure. Rather, it is caused by uplift (vertical), suctional (pressure-differential) and torsional (twisting) forces. High horizontal pressure of the windward side of a structure, for example, is accompanied by suction on the leeward side. In addition, the roof is subject to downward pressure and, more important, to uplift. Houses that fail usually fail because the devices that tie their parts together fail.

All structural members should be fastened together on the assumption that about 25 percent of the vertical load on each member may be a force coming from any direction.

Structural integrity is also important if it is likely that the building may eventually be moved.

The amount of force the wind exerts on a building can be modified by several factors, which must be considered in building design. For instance, the pressure on a curved surface, such as a cylinder, is less than the pressure on a flat surface. In addition, wind velocities increase with height above the ground, so a tall structure is subject to greater pressure than a low structure.

COMMUNITY CASE STUDY 1: ATLANTIC BEACH, NC

Community Overview

Atlantic Beach is located on the eastern end of Bogue Banks, an east-west trending island in the North Carolina barrier island system Figure AB1). The amount of land area in Atlantic Beach is 5.95 km^2 and the amount of surface water is 0.471 km^2.

Bogue Banks extends from 34° 38'30''N, 77° 06'00''E to 34° 41'30''N, 76° 40'30''E. The 40 kilometer-long arcuate island is situated between two tidal inlets: Bogue Inlet on the west and Beaufort Inlet on the east. Landward of the island is Bogue Sound, a shallow lagoonal system that ranges in width from .4 to 2.4 kilometers. The predominant littoral current at Atlantic beach is from west to east (Stanczuk, 1975).

Development

During the 1930s the tract of land surrounding the "circle" was platted with lots and streets extending out to the east and west. Streets running east and west were called Boulevards and named for local geographical features. Those running north and south were called Avenues and named in honor of towns and cities in North Carolina. Lots were sold, and in 1932 the first cottage was built (Town of Atlantic Beach, 2001).

The town was officially chartered in 1937 (Atlantic Beach Land Use Plan, 1996).

Over the last 30 years, Atlantic Beach has evolved from a predominantly vacant landscape to a predominantly developed community. Rapid and uncontrolled development in Atlantic Beach has resulted in narrowed dunes, filled marshlands, finger canals and removal of most native vegetation (Pilkey, 1998). During this time, significant areas of Bogue Sound were bulkheaded and filled, and a significant amount of development took place on small lots unsuitable for septic systems.
During the 1980s, construction in Atlantic Beach was dominated by multi-family units. Since that time, single-family units have become the leading type of dwelling unit constructed (Atlantic Beach, 1996).
The 1995 construction value for all residential dwelling units was $2,644,721.

Today, Atlantic Beach is a mixture of commercial and residential uses that are primarily seasonal and resort oriented. The majority of commercial development is located along NC 58, on both sides of the Causeway and in an area known as the "circle." Most of the town's commercial development is old and is showing signs of deterioration (Atlantic Beach, 1996).
As of 1996, approximately 72 acres of vacant land remained for development. The town has projected that its remaining vacant land could accommodate an additional 750

FIGURE AB 1: Aerial View of Atlantic Beach, NC dwelling units, and that build-out would occur sometime during 2010 and 2013 (Atlantic Beach, 1996).

Projected Development Trends

During the next 20 years, public land use changes in Atlantic Beach may include redevelopment of the "circle" and construction of a central sewer treatment and collection system. These changes will likely increase property values, promote the conversion of existing mobile home parks to permanent residential dwelling units, increase traffic congestion and allow for the dispersion of commercial development.

Population

During the period 1980-1994, the permanent population of Atlantic Beach increased 241%, from 941 to 2,267 persons (Atlantic Beach Land Use Plan, 1996). In 1999, the population of Atlantic Beach was 2,320 and is expected to reach 3,050 by 2003 (OSBPM, 2001). The town's peak seasonal population is approximately 11 times the permanent population (Atlantic Beach Land Use Plan, 1996).

Transportation

There are approximately 23 miles of roads in Atlantic Beach. Sixteen miles are town owned and maintained, 6 miles are state owned and maintained and .88 miles are privately owned and maintained (Atlantic Beach Plan, 1996).

Atlantic Beach is connected to Morehead City, on the mainland, by a fixed, high-span bridge that was constructed in 1970 (Stanczuk, 1975).

Several areas of the town experience congestion (especially during peak season) and poor emergency vehicle access. These areas include the Causeway, the Circle, NC 58 and the Money Island subdivision where streets are improperly aligned.

Shoreline Changes

Dune stabilization projects on Bogue Banks began in the late 1930s. Although the intent of dune stabilization is to protect development from storm wave damage, stabilized dunes also act as dikes, preventing storm overwash from reaching the interior or back-side of the island. This, in turn, eliminates new sand from being deposited across the island, resulting in a general increase in erosion.

The first bulkhead in Atlantic Beach was built in 1956 (bulkheads are vertical structures, located at the dune line, that are built to prevent dune erosion and protect development from wave action). While bulkheads often do prevent dune erosion, they also discourage dune accretion. Bulkheads tend to reflect wave energy which can lead to scour at the toe of the bulkhead. As this scoured material is removed, the slope of the beach decreases and the lower beach face may eventually become completely inundated with increasing frequency. When the scour becomes great enough, the structure can be undermined.

Tidal currents flowing through Beaufort Inlet rapidly eroded the high water line in Atlantic Beach between 1939 and 1953. The sound side of Atlantic Beach had an erosion rate of approximately 1 foot/year during this period.

Atlantic Beach experienced eight hurricanes between 1953 and 1958, including Hurricane Hazel in October, 1954. Hazel caused significant beach and dune erosion and extensive property damage. Although still rapid, erosion at Fort Macon slowed to half of what it was from 1939 to 1953.

In the early 1960s, a jetty was built at Fort Macon, and by 1971, most of Bogue Banks was experiencing an accreting shoreline. This apparent reversal of erosion may have resulted from fewer major storms along with increased dune stabilization. Erosion along the sound-side of Bogue Banks, however, continued during this time.

Geology/Morphology

Carteret County is underlain by an eastward-thickening wedge of Pleistocene age sediment deposits ranging from 2,000 feet thick in the northwest portions of the county to almost 7,000 feet thick beneath the easternmost sections of offshore beach (Figure AB2). Shell fragments and calcareous material are consolidated into a limestone at a depth of less than 120 feet west of

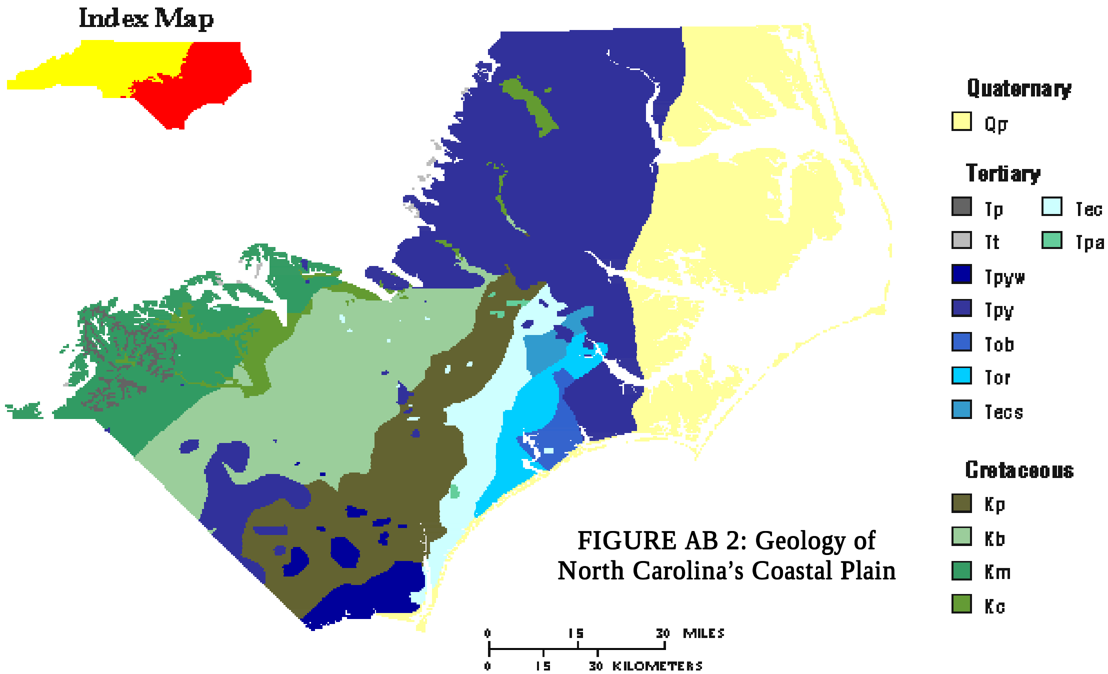


FIGURE AB 2: Geology of North Carolina's Coastal Plain

Morehead City, and at increasing depths further eastward. Microfossils indicate that the uppermost consolidated limestone is probably part of the Yorktown Formation (Atlantic Beach Plan, 1996).

Hazardous Events/Processes

Atlantic Beach is subject to hurricanes, tropical storms and extratropical cyclones. Due to its east-west orientation and the proximity of Cape Lookout, however, Atlantic Beach is somewhat sheltered from large storm waves that predominate from an east-northeasterly direction (Stanczuk, 1975). The hazardous processes of interest in Atlantic Beach are storm surge and storm overwash.

Hazard Geoindicators

As previously discussed, hazard geoindicators are local geomorphologic features that can, and do, influence coastal processes. The primary hazard geoindicators found in Atlantic Beach include:

Topographic Geoindicators

Elevation

The average elevation of Atlantic Beach is eight feet above sea level. The highest natural elevation is approximately 20 feet in a residential area immediately east of the Circle (circled area in Figure AB4). At the Circle itself, the central dune ridge was completely removed for development.

Because of its low elevation, approximately half of Atlantic Beach is located within either a V-or A- NFIP Flood Zone (Figure AB3). This means that a significant amount of the community is at or below the 100-year base flood elevation. A paved notch in the dune ridge immediately seaward of the Circle has exposed downtown Atlantic Beach to storm surge and makes the main evacuation route extremely vulnerable to storm surge flooding. Except for the dunes, slopes throughout the town are generally between zero and eight percent (Atlantic Beach Plan, 1996).

Vegetation

Vegetation native to Atlantic Beach includes *Spartina patens* (cord grass), *Ammophila breviligulata* (American beach grass), *Uniola paniculata* (sea oats), *Baccharis halimifolia* (eea myrtle), *Myrica cerifera* (wax myrtle), *Iva frutescens* (marsh elder), *Quercus virginiana* (live oak), *Juniperus virginiana* (red cedar), *Slex vomitoria* (yaupon) and *Spartina alterniflora* (smooth cord grass). All vegetation was removed from the area around the Circle to make room for development. Most of the remaining areas of intact maritime forest in Atlantic Beach are located on scattered parcels north and south of NC 58 between Cedar Lane and the general area of the Ocean Ridge/NC 58 intersection.

Shoreline Geoindicators

Shoreline geoindicators include geomorphologic features of the ocean beach, the estuarine shoreline and the offshore continental shelf. This category of geoindicators influences storm surge height, storm wave height, wave energy and storm surge ebb flow.

The Ocean Beach

The average, long-term erosion rate in Atlantic Beach is approximately 2 feet/year (Pilkey, 1998). The ocean beach in Atlantic Beach is, however, artificially maintained and two nourishment projects have placed approximately 6 million yds^3 of sand on the beach during the past 15 years.

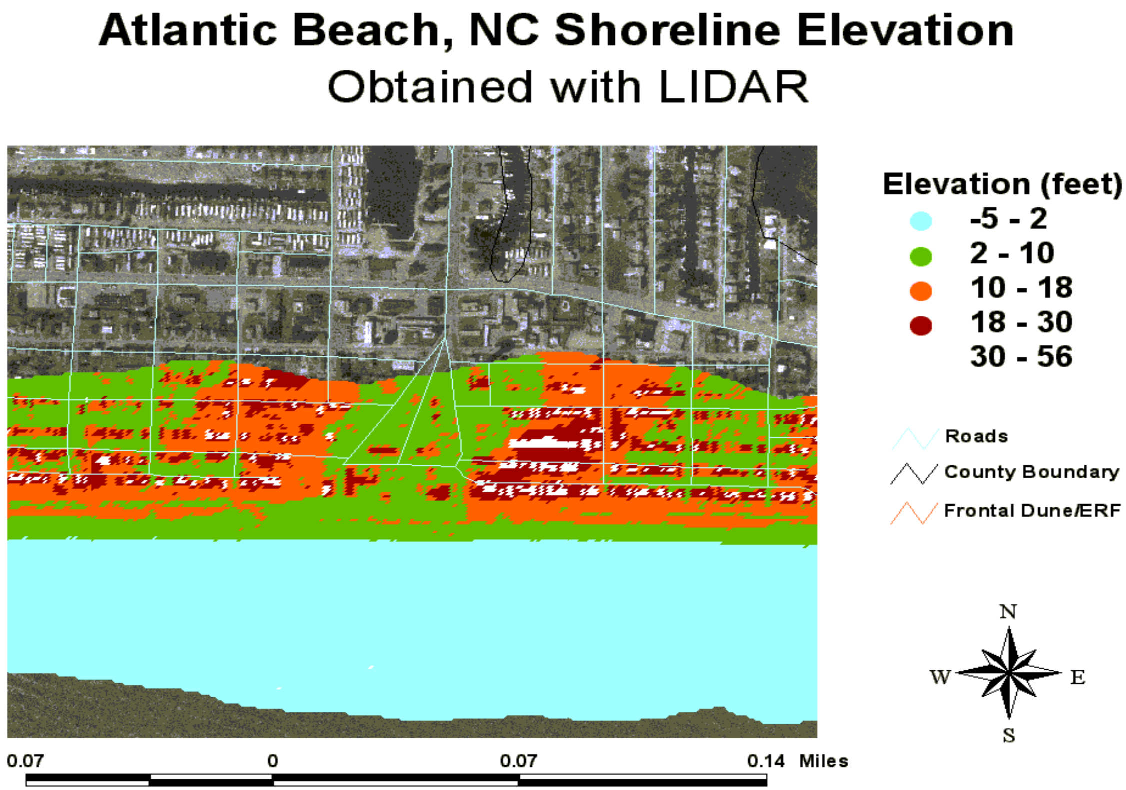


FIGURE AB 4: LIDAR Elevation Data for the "Circle" Area of Atlantic Beach

FIGURE AB 3: Flood Zones for Atlantic Beach, NC

In 1986, approximately 2.5 million yds^3 of sand that was dredged from Beaufort Inlet was placed on the beach from near the Triple S Pier west to just beyond the Atlantic Beach municipal boundary (Bush, 1996). The beach was widened and sand fencing has resulted in modest dune growth. Another 3.5 million yds^3 of dredged sand was placed on the beach in the same general vicinity in 1994 (BBBAP, 2001).

The beach currently ranges in width from 10 to 120 meters from the dune line to the high water line.

Primary/Frontal Dunes

Atlantic Beach is fronted by a discontinuous, staggered dune line that ranges in height from 0 to over 20 feet. Because the sediment that was dredged from the inlet and deposited on the beach had a high mud content, dune and beach erosion scarps are common, especially east of the circle.

Bathymetry

The bathymetry of eastern Bogue Banks is illustrated in Figure AB5 to the right. Atlantic Beach is located at the northern edge of Onslow Bay, a microtidal environment with a mean tidal range of about 1 meter (Figure AB 6 on the next page). Hindcast wave data (WIS studies) indicates a mean wave height of 1.1 meters, with a 7 second period.

The Onslow Bay shelf is sediment-starved and the introduction of new sediment to

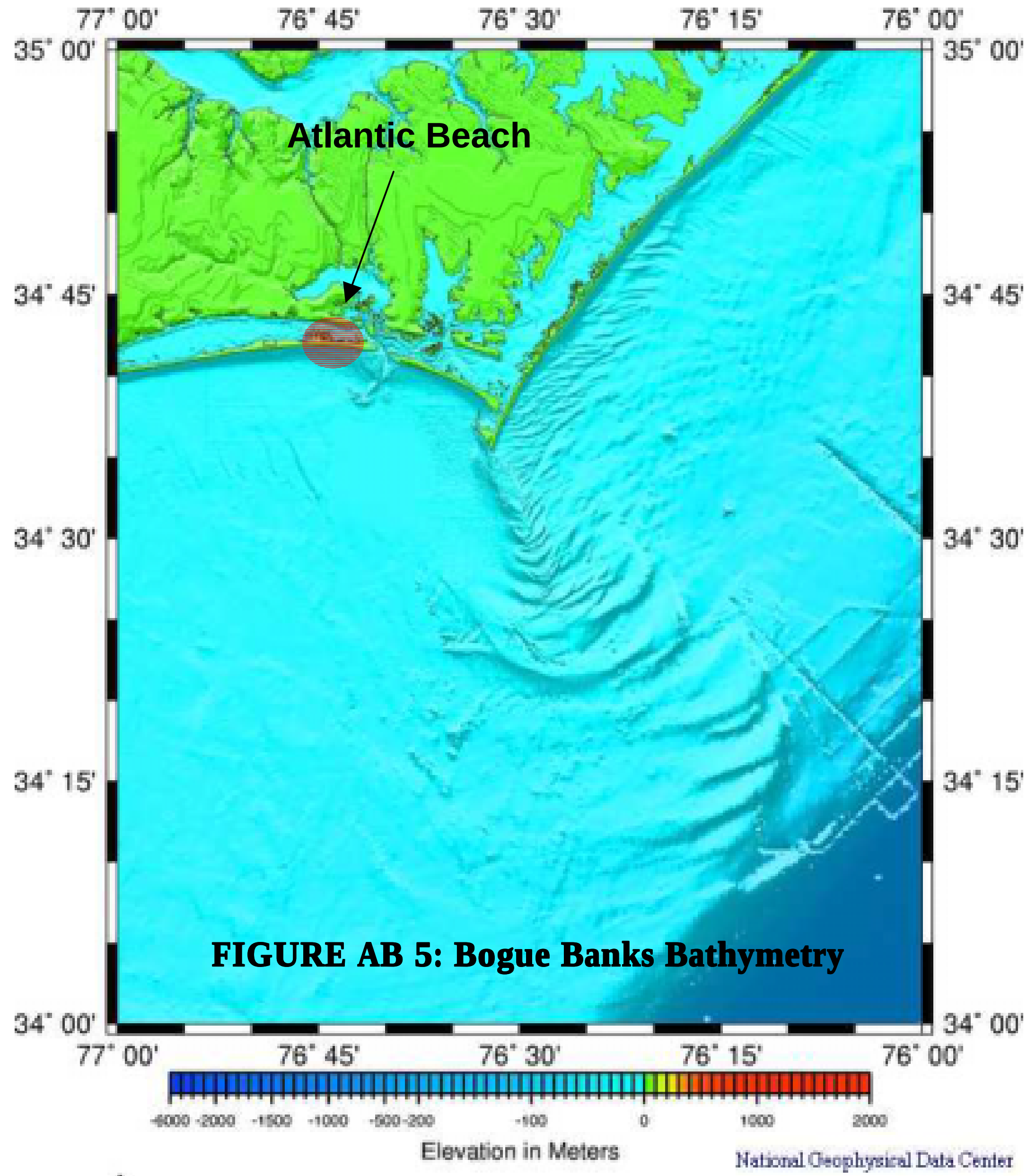


FIGURE AB 5: Bogue Banks Bathymetry

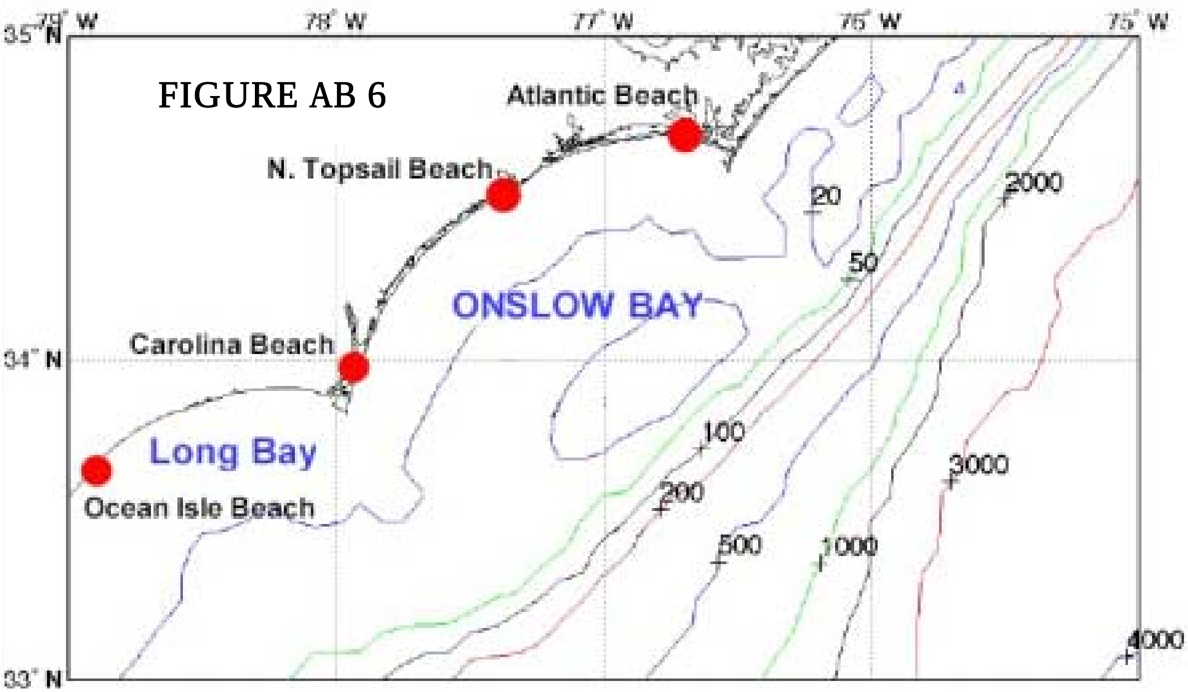


FIGURE AB 6

Onslow Bay is negligible due to: 1) no fluvial input (coarse sediments are trapped in the upper estuarine system) and 2) minimal sediment exchange between adjacent shelf embayments. Onslow Bay shelf sediment cover has been classified as residual (meaning it has been derived from the erosion of underlying sediments and rocks (USGS, 1998).

Analysis of geophysical data from the shoreface and inner shelf of northern Onslow Bay (Bogue and Shackleford Banks) suggests a direct coupling between shoreface geologic framework and subaerial barrier island morphology. Sidescan-sonar imagery collected in May 1997 indicates that the shoreface seaward of these regressive barrier islands is fundamentally different from the transgressive barriers that line much of Onslow Bay.

On Bogue and western Shackleford Banks, the entire shoreface is composed of uniform fine sand. The shoreface off eastern Shackleford Banks, however, is covered with coarse-grained, rippled sediments interpreted to be products of reworking in a sediment-starved shoreface environment. This change in shoreface morphology corresponds directly to a change in barrier island morphology from regressive (sediment-rich) to transgressive (sediment-starved). The transgressive shoreface segment off Shackleford is similar to the shoreface off other transgressive barriers in Onslow Bay such as Wrightsville Beach and Topsail Island.

Three possible explanations for the features observed on the eastern Shackleford Banks shoreface have been proposed:

1. they are rippled scour depressions that result from bottom scour by strong, channelized offshore-directed flows (if true, then the rippled areas indicate the presence of sediment transport conduits between the beach and the shelf);

2. the linear rippled areas are sediment-starved, flow-transverse bedforms formed and maintained by longshore currents. The proximity to Barden's Inlet suggests longshore or tidal currents may be locally important.

3. the coarse sediments are lag deposits from relict estuarine tidal channels and thus indicate that the shoreface is actively eroding.

Storm Surge

Estimated hurricane storm surge elevations for Atlantic Beach are illustrated in Figure AB 7 on the next page. Surge elevations are for a fast-moving hurricane and are derived from the SLOSH model.

The Estuarine/Backside Shoreline

The soundside shoreline of Atlantic Beach is largely characterized by an eroding salt marsh, canals that were dredged to provide access to Bogue Sound and artificial fill used for development.

Inlet Geoindicators

Atlantic Beach has two inlet hazards: 1) Beaufort Inlet and 2) a relict inlet that persisted from the mid 1700s until about 1800 (Bush, 1996). The central portion of Atlantic Beach including Morehead Avenue, the main road leading to the causeway and mainland, is built on the natural fill of this inlet's tidal delta.

Massive dune ridges distinguish the island from the low elevation historical inlet area. Navigation dredging of Beaufort Inlet began in 1850 with the opening of the port terminal at Morehead City. Subsequent dredging in 1910, 1936 and 1960 deepened the channel from its original depth of 15 feet to a depth of 35 feet.

In 1961 the outer channel of Beaufort Inlet was deepened to 35 feet from its natural depth of 15 to 18 feet. Twice since, the channel has been further deepened and lengthened and is now maintained at a depth of 45 feet.

Each year the US Army Corps of Engineers removes 700,000 to 1,000,000 cubic yards of sand from the inlet which is deposited at an off shore site. The total amount of sand in the inlet's ebb tidal delta is estimated to be 33 million cubic yards (USACE, 2001).

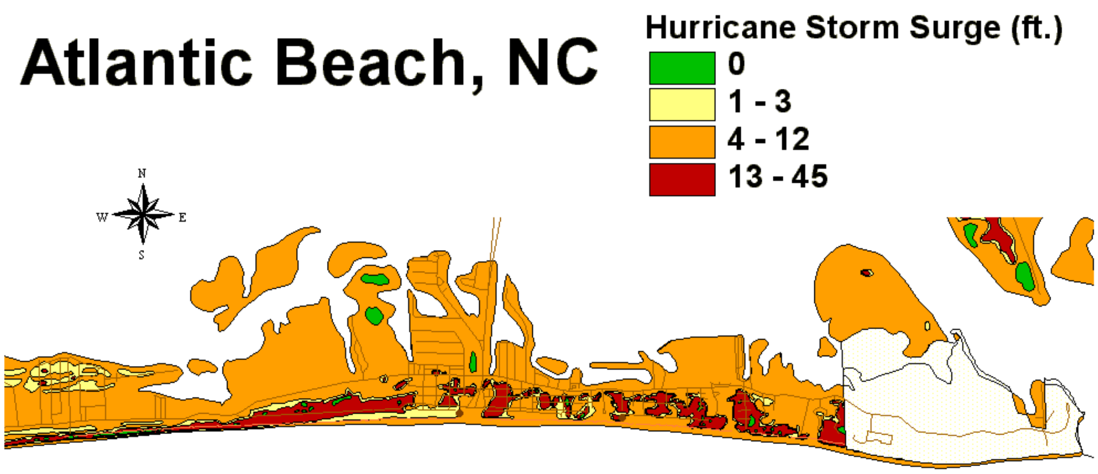


FIGURE AB 7: Hurricane Storm Surge Elevations for a Fast Moving Hurricane (source: NC

Non-Shoreface Geoindicators

There are eleven different soil associations found within Atlantic Beach, most of which have some type of development limitations.

Mitigation Recommendations

Atlantic Beach contains areas that range from extreme risk to low risk. Figure AB 8 provides a detailed illustration of risk and hazard geoindicators in Atlantic Beach. Figures AB9 and AB10 provide a more generalized overview of risk.

Areas of extreme risk are indicated in Figures AB8 and AB9 and include the immediate open ocean shoreline, land immediately west of Fort Macon State Park, the Circle, the Causeway and the area known as the "Finger Canals."

Because of the ongoing beach nourishment project, shoreline migration is not considered a priority hazard at this time. Even though the beach is artificially maintained, oceanfront properties and low areas are still subject to storm surge, flooding and storm overwash.

While erosion problems associated with a migrating shoreline in Atlantic Beach are not addressed in this section, it does not mean that erosion will not become an issue once nourishment ceases, nor does it mean that erosion should not be considered during the development process.

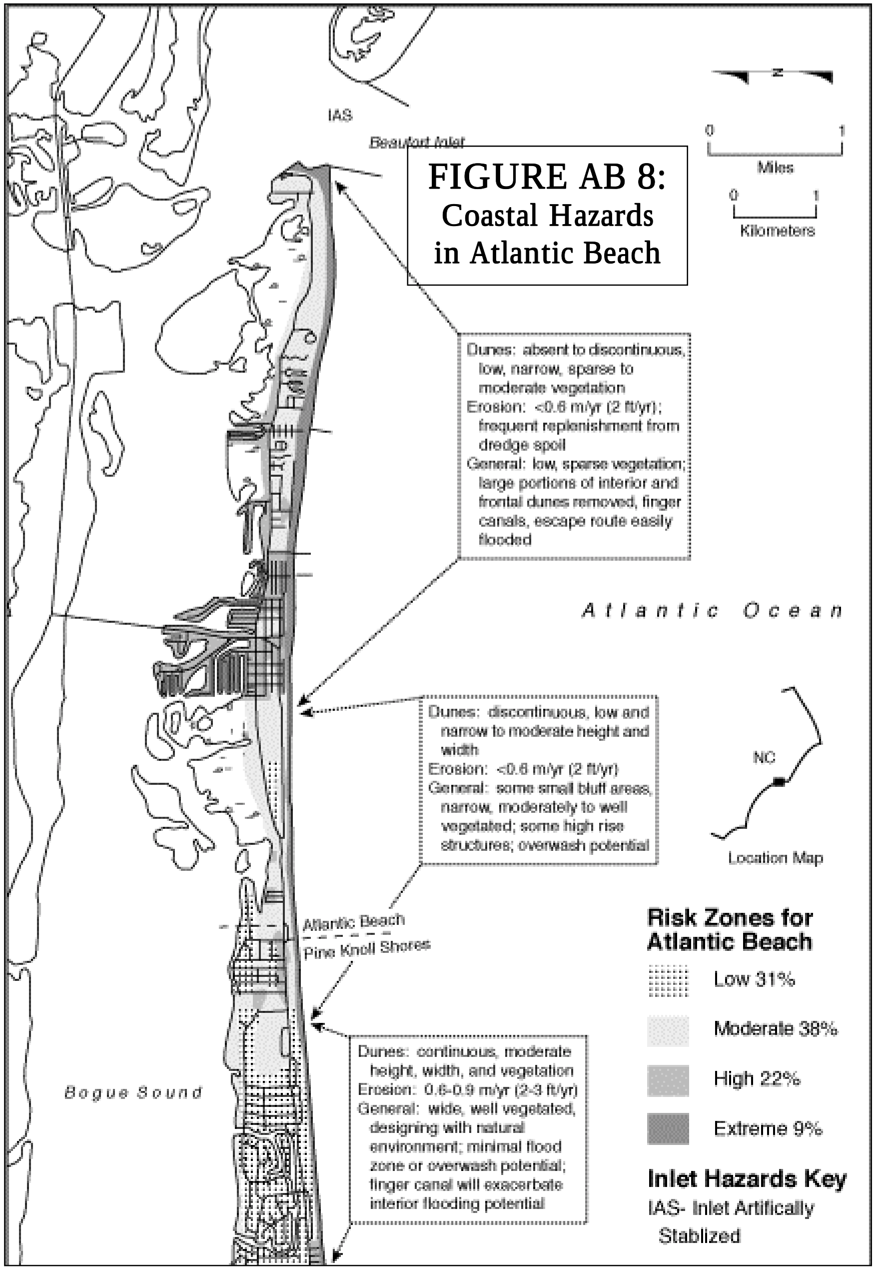


FIGURE AB 8: Coastal Hazards in Atlantic Beach

A priority hazard mitigation recommendation for Atlantic Beach is to establish more stringent community-wide building restrictions in the event a central sanitary sewer system is constructed.

Studies have shown that central sewer systems result in an increase in building density and size. With established development restrictions already in place, the town can significantly reduce the amount of future development that becomes vulnerable to coastal storm processes.

Open Ocean Shoreline

Even though the open ocean beach in Atlantic Beach is artificially maintained, development immediately adjacent to the shoreline remains at extreme risk from a major hurricane as well as from extra tropical cyclonic activity.

General Implementing Actions:

- Construct and maintain a continuous frontal/primary dune field along the entire oceanfront of Atlantic Beach.
- Increase the volume of the frontal/primary dune field using compatible sand from a source other than the beach.
- Establish dune vegetation using native species.
- Plug all dune gaps and prevent the creation of new gaps.
- Construct dune crossovers, both pedestrians and vehicular, where access to the beach is desired.

- Allow sand, deposited by storm surge and storm overwash, to remain in place.
- Establish a "dune migration zone" and establish staggered setbacks distances based on this zone so substantially damaged structures are rebuilt in a nonlinear fashion.
- Increase building density and building size restrictions on all oceanfront lots.
- Establish a program to fund the purchase of lots containing "imminently threatened" structures and lots with substantially damaged structures - all publicly-owned lots should remain as permanent open space.
- Investigate the possibility of developing a long-term retreat/relocation/evacuation plan for all oceanfront structures in the event that beach nourishment is discontinued

Area Immediately West of Fort Macon State Park

This area of Atlantic Beach is extremely low and has experienced numerous storm overwash episodes. It is also possible that an inlet was once located in this area.

General Implementing Actions:

- Increase interior sand volumes by adding sediment from an off-island source
- Relocate/remove structures and maintain as passive open space
- Allow overwash sediment to remain in place
- Plant and encourage the growth of native vegetation

The Circle

- Construct a substantial frontal/primary dune and plant native vegetation
- Increase interior sand volumes by adding sediment from an off-island source
- Relocate/remove structures and maintain as passive/active open space
- Allow overwash sediment to remain in place
- Plant and encourage the growth of native vegetation

The Causeway

- Elevate the existing roadbed
- Consider building an elevated causeway

"Finger Canals"

- Fill-in existing finger canals
- Shorten existing canals by infilling the heads of each canal
- Construct sediment mounds at the landward ends of shore-perpendicular canals and at other potential points of breaching.

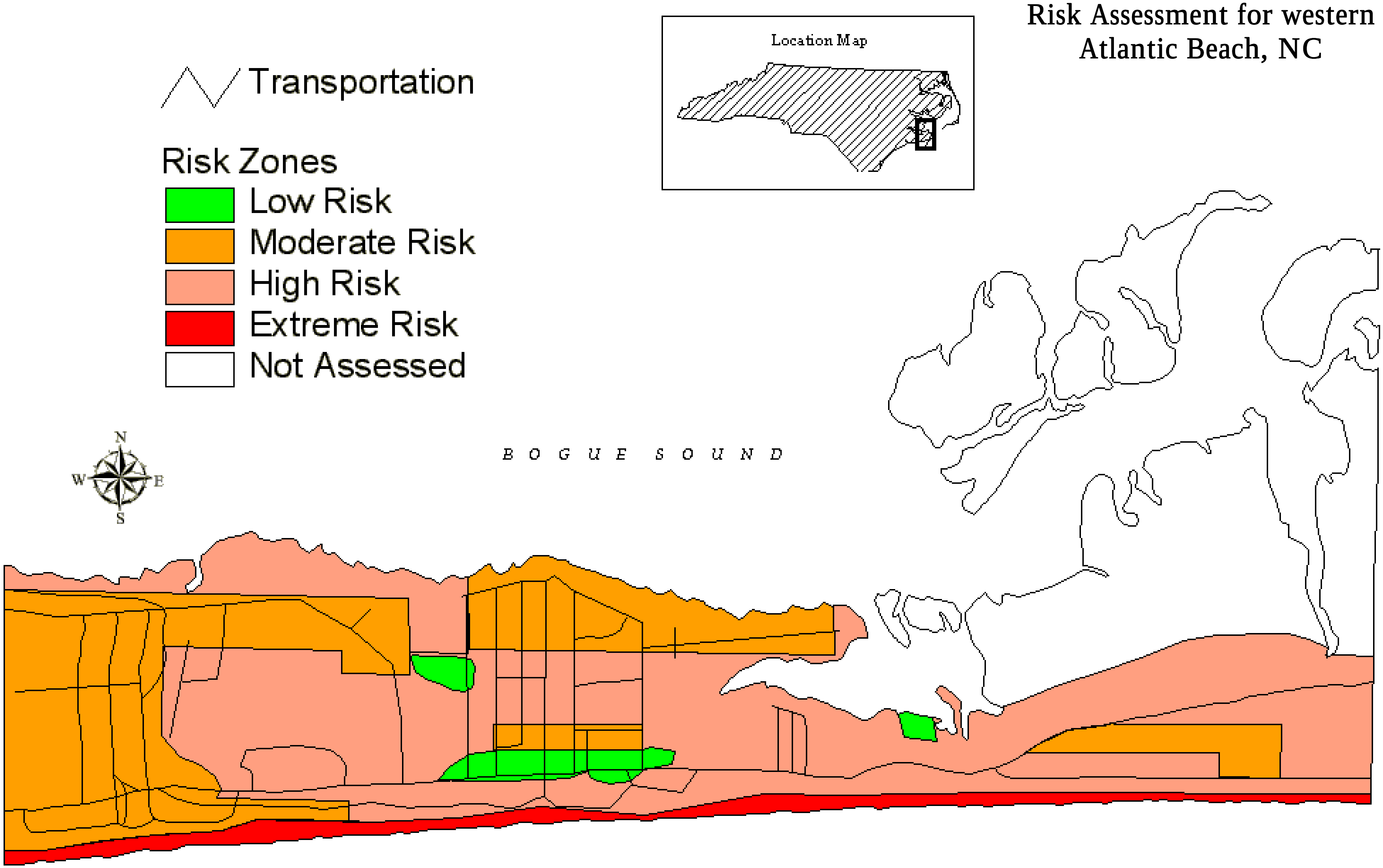
Post-Storm Redevelopment Issues

A major storm could have profound impacts upon Atlantic Beach, and a Category 3 or greater hurricane would result in substantial damage town-wide. Current town policy allows for the reconstruction of any structure demolished by natural disaster or by other causes in accordance with all applicable federal, state and local regulations (Atlantic Beach, 1996).

According to the town's 1996 CAMA Land Use Plan, it is town policy to "promote, foster and encourage the redevelopment of old, poorly-designed and underutilized areas" and that "redevelopment of these areas is preferred and deemed more important than development of currently undeveloped areas."

Actual development and redevelopment potential will be greatly influenced by construction of a central sewer system (Atlantic Beach Plan, 1996).

FIGURE AB 9:
Risk Assessment for western Atlantic Beach, NC



Dunes: continuous, moderate height, width, and vegetation
Erosion: 0.6 to 0.9 m / yr (2.0 to 3.0 ft / yr)
General: wide, well-vegetated, designing with natural environment; minimal flood zone or overwash potential; finger canal will exacerbate interior flooding potential

Dunes: discontinuous, low and narrow to moderate height and width
Erosion: less than 0.6 m / yr (2.0 ft / yr)
General: some small bluff areas, narrow, moderately to well vegetated; some high rise structures; overwash potential

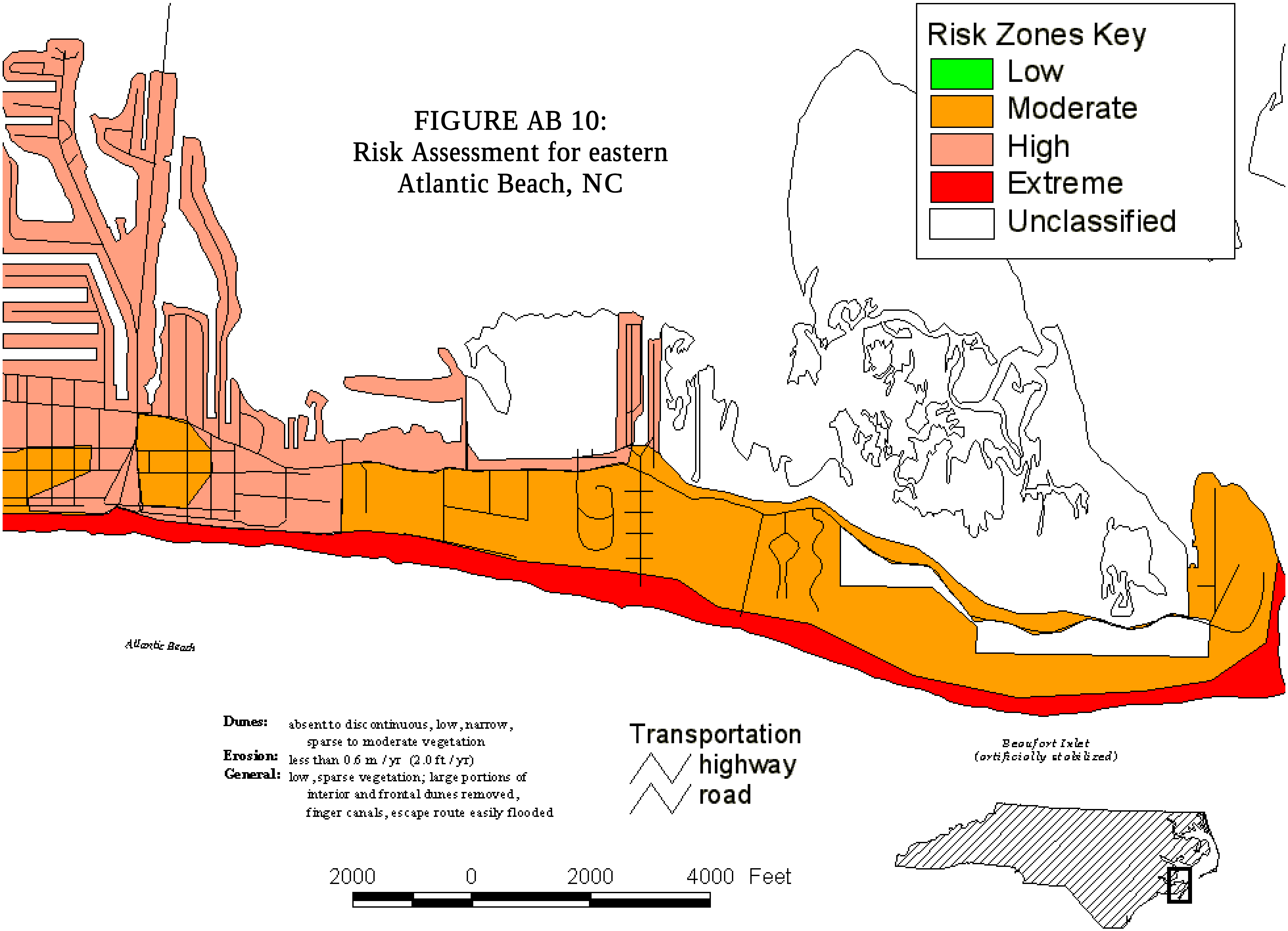


FIGURE AB 10:
Risk Assessment for eastern
Atlantic Beach, NC

COMMUNITY CASE STUDY 2: NAGS HEAD, NC

Community Overview

Nags Head is located on North Carolina's Outer Banks on a narrow spit situated between the Atlantic Ocean to the east and Roanoke Sound to the west. Within the Town is approximately 11.29 miles of oceanfront shoreline that stretches south from Eighth Street to the southern municipal boundary adjacent to the Cape Hatteras National Seashore.

Development

From its early beginnings in the 1800s, Nags Head has consisted predominantly of single-family cottages and a few hotels. Like all of the Dare County beach communities, Nags Head, especially during the mid- to late-1980s, experienced tremendous growth and development pressures. The most significant growth pressures in the Town are, and will continue to be, generated by seasonal resort development

The amount of land area in Nags Head is approximately 4,300 acres. As of 1997, 2,805 acres had been developed and 976 acres were unplatted, undeveloped, privately owned and subject to development. An additional 500 acres were in rights-of-ways (ROW) and not available for development (Nags Head, 2000). The Town has 5,080 dwelling units, of which 62 percent are single-family and duplex units.

Nags Head can be divided into two sections: North of Whalebone Junction and south of Whalebone Junction. Whalebone Junction is the area in which State Highway 64 intersects with State Highways 12 and 158.

The area south of Whalebone Junction is relatively wide but low in elevation with the foredune having the highest elevation. Development in this area is limited to Old Oregon Inlet Road and consists primarily of single family dwellings. A large hotel and several multi-unit condominiums are situated just south of the intersection of Highways 12 and 64.
In the area north of Whalebone Junction, development extends from the oceanfront across the island to the sound. This area also contains all of Nags Head's commercial development.

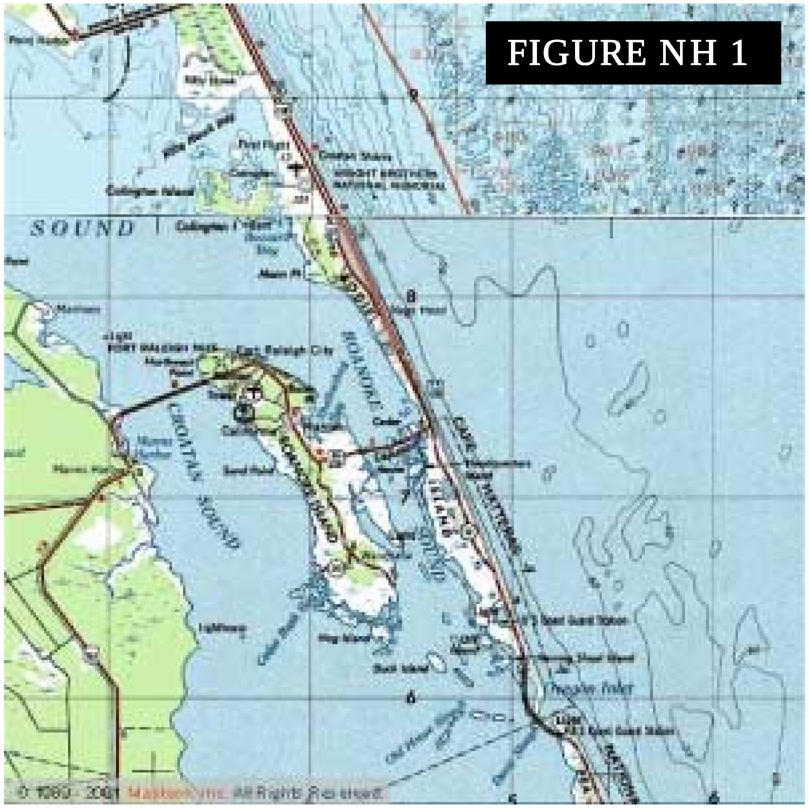


FIGURE NH 1

Residential

As of 1997, the Town had 5,080 dwelling units, 3,129 of which were single-family units. Over the last twenty-one years, on average, 83 percent of new dwelling units built have been single-family or duplex. However, over the last ten years, 97 percent of the dwelling units constructed have been single-family and duplex units. At build-out, which is projected to be in 14 to 18 years the Town will have approximately 6,914 dwelling units, an increase of 1,834 from what the town has now (Nags Head, 2000).

Due to development on lots that were platted before the incorporation of the Town in 1961, the density of lots developed prior to 1980 is higher than the density permitted by the current Zoning Ordinance.

The typical minimum residential lot size has gradually increased from 7,500 square feet in 1962, to either 15,000 or 20,000 square feet today. The average lot size for single-family development between 1985 and 1996 was 12,000 square feet. As more of the older, smaller lots of record are used up, the average lot size will increase and so, too, will the size of the structures on those lots. In 1986, for example, the average size of a new single family structure was 1,398.45 ft^2. In 1996, it was 2,442.41 ft^2 (Nags Head, 2000).

Hotels and Motels

There are 766 hotel and motel units along the Nags Head oceanfront. Many of the structures housing these units are one story high, with a few three stories high. Notable exceptions are the Comfort Inn (built in 1974) which is seven stories and approximately 65 feet high and the Nags Head Inn which is four stories and fifty feet in height. The last hotel to be built on the oceanfront is Nags Head Inn which was constructed in the mid-1980s.

Little undeveloped land is available to build new hotels and motels along the oceanfront. In all likelihood, any new construction of hotels and motels on the oceanfront will involve redevelopment with the recombination of existing lots into large parcels that can accommodate these uses. Both uses are allowed by the Town's Zoning Ordinance.

Commercial and Non-Residential

Between 1974 and 1990 five major shopping centers were built (Surfside Plaza, 24,600 square feet; Nags Head Station, 18,000 square feet; Satterfield Landing, 44,700 square feet; Outer Banks Mall, 138,600 square feet; and Soundings Factory Outlets, 84,000 square feet). From 1990 to 1997, six projects in excess of 10,000 square feet were built.

Nearly all of the commercial development in Nags Head is located along South Croatan Highway (US 158) and most of the multi-family and motel development is located on or near the oceanfront (Nags Head, 2000).

Of the structures that exist east of NC 12 and NC 1243, 51% were built before 1972 when building codes did not specifically address enhanced coastal construction methods and materials.

Zoning Districts

The Town of Nags Head has ten zoning districts and several areas of extraterritorial jurisdiction. Some of the districts such as R-1, R-2 and R-3, are set aside primarily for residential development. Districts such as the C-2 District allow a mixture of commercial and residential uses, while other districts, such as the C-3 (Commercial Services District), are very limited in what commercial uses will be allowed.

R-1: Low Density Residential District

The R-1 District was intended to encourage the development of low-density residential neighborhoods. There are two R-1 residential districts in Nags Head. One is located along the oceanfront between Jockey's Ridge State Park and Diamond Street adjacent to South Virginia Dare Trail. The other R-1 District area is off the Nags Head-Manteo Causeway and includes Pond Island, and portions of Cedar and Horse Islands.

There are approximately 58 acres of undeveloped land in R-1. A large portion of this undeveloped land (54 acres) is located on Cedar and Horse Islands, and the land areas on the south side of the Causeway near Pond Island. The tracts along the Causeway appear to contain a significant amount of wetlands. Excluding these parcels, there are ten lots available for development. With the exclusion of these parcels, 95.8 percent of the land area in R-1 is developed.

R-2 Zoning District

The R-2 District was intended to encourage the development of moderate-density residential neighborhoods with a mix of permanent and seasonal residents, and also to serve as a transition zone between the low-density areas and more intensely developed areas. There are three R-2 residential areas.

The northern area is on the west side of Croatan Highway and includes Carolinian Colony, Oak Knoll Estates, Nags Head Acres, Vista Colony West and the Hills at Nags Head subdivisions. A second area is west of US 158, between Soundside Road and the Outer Banks Mall and includes South Ridge and Old Nags Head Cove subdivisions. The third area is generally south of Whalebone Junction and includes most of South Nags Head including the oceanfront. Permitted uses in R-2 include single-family and duplex houses, and municipally owned public access facilities.

There are 881 acres in R-2 of which 61 percent is developed. Of the developed land, 92 percent of the land area is devoted to single-family and duplex residential uses.

R-3: High Density Residential District

The R-3 residential district was established as an area for high-density residential development. This district also provides for development of less intensive residential uses as well as compatible supporting uses. There are four R-3 areas within the town.

The first two areas are in the northern part of town between Wrightsville and Memorial Avenue. One area is from Eighth Street to an area just past Atlas Street, and the other R-3 area is between Gallery Row and Abalone Street, The largest R-3 area is comprised of parts of Vista Colony, Vista Colony South, and most of the area south of Dowdy's Amusement Park between the highways. This includes the Enclaves subdivision, the area around Linda Lane, part of Nags Head Shores subdivision, and the Stronach Tract which is located between US 158, Fresh Pond Avenue, and Hollowell Street. The fourth area includes the Town Hall Complex, Hawk's Nest subdivision just to the south, and an undivided parcel to the south of the Hawk's Nest subdivision. There are 116 acres in R-3 of which 59 are developed. Of the developed land, 95 percent has been developed primarily as single-family residences.

Commercial Zoning Districts

The town has five commercial zoning districts: CR, C-2, C-3, Village Commercial and C-4.

The CR District is an area in which the principal use of the land is for intensive recreational purposes and for those types of developments which, by their nature, are best located in close proximity to the Town's ocean beaches. The district also provides for less intensive recreational uses as well as compatible supporting uses. As of January 1, 1997**,** 34 lots remained undeveloped in this district which consists of four areas along the oceanfront.

The C-2 District is 465 acres in size, provides for the grouping and development of commercial facilities and is distributed in several areas throughout the town. The largest section of C-2 is between US 158 and Virginia Dare Trail from Jockey's Ridge State Park south to South Nags Head. Other C-2 areas include both sides of US 158 from Eighth Street to Villas Dunes Drive on the west and from Eighth Street to Dowdy's Amusement Park on the east; between Memorial Avenue, Fresh Pond Drive and Virginia Dare Trail and on the west side of US 158 from the southern boundary of The Village at Nags Head south to the Nags Head–Manteo Causeway.

The C-3 Commercial Services District is located west of the Satterfield Landing Shopping Center between Eighth Street to the north and Carolinian Colony subdivision to the south. The district is 29.7 acres in area, is 89.5 percent developed and is the only district in Nags Head that does not permit single-family houses.

The Village Commercial District permits the development of residential areas of low-to moderate-density with a mixture of professional commercial activities of limited size.

There is one C-4 District located in an area just south of Atlas Street extending to an area just south of Gallery Row between

Wrightsville and Memorial Streets. The district is 5.7 acres in size and is 68.4 percent developed.

SPD-20: Special Planned Development District

The Special Planned Development District was created to permit development compatible with the environmentally sensitive nature of the unique coastal land forms contained in this district. The largest portion of this district contains Jockey's Ridge State Park that has been designated by the North Carolina Coastal Resources Commission as a unique coastal geologic formation area of environmental concern and as a National Natural Landmark by the United States Department of the Interior.

The northwestern portion of the district borders on Nags Head Woods. This district is characterized by unique topographical and vegetative features including vegetated and unvegetated dunes, migrating sand dunes and a pine forest.

There is one SPD-20 District that encompasses the North Ridge subdivision, the Villa Dunes subdivisions (west of the Outer Banks Worship Center) and the Villas Townhouses as well as and Jockey's Ridge State Park.

The SPD-20 District is 534.6 acres in size with 417 acres in public and governmental ownership (Jockey's Ridge State Park). The predominant use in the district, apart from the State Park, is residential. There are 90 lots which meet the Town's development criteria for single-family homes with some vacant parcels within or adjacent to Jockey's Ridge State Park.

SED-80: Special Environmental District

The SED-80 District includes Nags Head Woods, an irreplaceable maritime forest that occupies the northwest corner of Nags Head, and one of a few remaining maritime forests in North Carolina. Nags Head Woods was recognized for its environmental significance in 1974 when it was designated a National Natural Landmark by the US Congress.

SPD-C: Special Planned Development-Community District

The Town has one SPD-C District, the Village at Nags Head. The Village located between the Atlantic Ocean and Roanoke Sound, with Old Nags Head Cove subdivision to the north and Forrest Street to the south. There are approximately 373 acres in SPD-C.

Planning for The Village at Nags Head Special Planned Development-Community District began in the 1970's. The original plan was amended and adopted by the Nags Head Board of Commissioners on June 1, 1981. At this time, the land was under the ownership of the Epstein family and was known as the "Epstein Tract." The Epstein heirs sold the tract to Home Savings and Loan of Rocky Mount (HSL) in 1984. The Ammons Dare Corporation purchased the tract from HSL in early 1986.

On July 16, 1986, the Town approved the Master Plan and Development Standards for The Village at Nags Head. This Master Plan established development and density standards for The Village at Nags Head, five single-family designations, three multi-family designations, two hotel districts, two commercial areas, a beach and tennis club, a golf course, sound access areas, Sea Pointe duplex standards, and numerous areas designated as open space. The Master Plan also established standards for an institutional district and Townhouse 1 District standards.

While multi-family and hotel standards were developed, no multi-family or hotel buildings (other than the Quay, which was built before 1986) have been built. The residential density has been less than what was originally approved in the 1986 Master Plan.

To date, there are 598 lots created for residential (single-family and duplex) development. Of those 598 lots, 218 remain undeveloped. In addition, parcels L-1 and L-2, between the Outer Banks Mall and Old Nags Head Cove, which have not been subdivided, are the last remaining residential parcels. The approved Master Plan allows for a maximum of 101 dwelling units on these parcels. In addition to the undeveloped residential lots, there are three undeveloped parcels (6.7 acres) in the Commercial 1

District and 9 undeveloped parcels (9.4 acres) in the Commercial 2 District. The Small Hotel Parcel (6.1 acres) also remains undeveloped.

The Village at Nags Head currently has architectural review standards, a State-approved stormwater control plan and buffering and vegetation standards. The 1986 Master Plan has been amended and became part of the Town's Zoning Ordinance on November 3, 1993.

Ocean and Sound Waters Zoning District-Extraterritorial Jurisdiction (ETJ)

The General Statutes of the State of North Carolina allows municipalities to extend zoning and planning jurisdiction into unzoned county areas up to one mile beyond their municipal boundaries. Nags Head has established extraterritorial jurisdiction one mile out into the Atlantic Ocean, one mile west of the Town's estuarine shoreline, one mile south of US 64-264 on the Causeway, and one mile west of the Town boundary line in South Nags Head. With the exception of land within the Cape Hatteras National Seashore and some islands in the sound, the remainder of the ETJ area is water.

The Ocean and Sound Waters District was established to provide for the use of the ocean and sound waters, including islands, that adjoin the Town to ensure the continued scenic, conservation and recreational value that these waters provide to the Town, its residents, visitors and surrounding area.

Uses allowed within this district include: non-commercial recreational activities, commercial recreational activities that are land based in Nags Head, single-family dwellings, piers and docks and other customary accessory uses. There are currently three "fish camps" or single-family dwellings on islands in Roanoke Sound within the ETJ area that have existed for a number of years.

Population

Nags Head was incorporated in 1961 and in 1970, there were only 414 permanent residents in the Town. By 1980 the population had more than doubled, and in the years between 1980 and July l, 1985, the permanent population increased an additional 80 percent. The 2000 permanent population of Nags Head is 2,700 - a 46.9% increase since 1990 - and the permanent population is projected to be around 3,580 in the year 2020 (OSP, 2001; Nags Head, 2000). Under existing development, the peak daily summer population is estimated to exceed 34,500 people.

Projected Development and Population Trends

Over the last 22 years there have been an average of 109 single-family dwelling units constructed per year. Using this figure, the 1,560 lots remaining for single-family development would be used up in 14.3 years. Following the growth patterns observed over the last twelve years, an additional 1,834 dwelling units will be added, giving a total of 6914 dwelling units assuming that there are no changes in zoning which would affect development intensities. There are currently 178 acres in the various commercial districts that can accommodate future growth. Based on previous development patterns, this land will be developed in twelve years (Nags Head, 2000).

As Nags Head continues to grow and develop, the size of its peak population will grow as well. An analysis of land availability, permissible development and building trends is used to estimate extent of future peak population and the demands that will be placed upon the natural and man-made environments in the Town.

The likely peak population that would result from maximum build-out, based on existing land uses, is estimated to be between 51,324 and 66,584 (Nags Head, 2000).

Transportation

The existing transportation system in Nags Head consists of two primary, shore-parallel roads. NC 12, which is closest to the ocean, is also known as Virginia Dare Trail and the "Beach Road." US 158 generally runs down

the center of Town and is known as Croatan Highway and the "Bypass."
In addition to these two roads, which are state maintained, there are numerous town-maintained roads running in an east-west configuration that connect NC 12 and US 158. In South Nags Head, south of Whalebone junction, NC 1243 (South Old Oregon Inlet Road) is a state-maintained road and the only major road within Nags Head that serves this area.

The NC Department of Transportation has completed a Thoroughfare Plan for the Outer Banks and suggests the following changes to facilitate traffic movement within the Town (specifically along NC 12):

1. Improve NC 12 with by an additional three feet of pavement on both sides.
2. Where there is currently a third turn lane on NC 12, the interconnecting road to US 158 should be widened to three lanes.
3. Gull Street and Lakeside Street should be three lanes from NC 12 to US 158. A signal should be placed at Gull Street to address access to the Soundings Shopping Center.

Shoreline Changes

Erosion rates vary widely along the Atlantic coastline of Nags Head. Average erosion rates for various sections of the beach range from two feet per year at Eighth Street to ten feet per year at the southern Town limits in South Nags Head. These rates are long term averages and acute, episodic events that cause erosion in excess of 100 feet are not uncommon.

Geology/Morphology

The geologic framework, physical dynamics, and recent human modification dictate the types of barrier islands that constitute the Outer Banks and their evolutionary development.

Sediment-rich coastal segments previously formed as complex barriers consisting of multiple seaward prograding beach ridges result in high, wide islands. Today, these complex islands are neither migrating landward nor accreting seaward; rather, erosion is the dominant process on both ocean and estuarine shorelines.

Sediment-starved coastal segments formed as simple overwash barriers consisting of thin Holocene sand perched on the interstream divides of Pleistocene drainage basins. Due to the geologic inheritance and evolutionary development, some of these sediment-starved barriers are presently collapsing with little chance of surviving in their present form.

Reconnaissance studies of the thick Quaternary section on the continental shelf adjacent to the Outer Banks have demonstrated numerous potential sand resources that occur in paleofluvial deltas and channels, cape-shoal structures and various stratigraphic lithofacies (Riggs, 2001).

Hazardous Events/Processes

Historic Storm Impacts

Hurricanes and severe coastal storms represent serious threats to life and property in Nags Head. Between 1890 and the present, North Carolina experienced 24 hurricanes, or an average of approximately one hurricane every four years. In addition to hurricanes, Nags Head is also subject to tropical storms and northeasters, such as the devastating Ash Wednesday storm of 1962 and Tropical Storm Dennis in 1999 that lingered off the Nags Head coast for a week before eventually making landfall south of Nags Head.

In an attempt to keep the beaches free of debris, the Town can declare structures which are storm damaged and in danger of collapsing a public nuisance. In addition, any structure which is located in whole or part in the public trust area can be declared a public nuisance and abatement procedures can be initiated by the Town.

Hazard Geoindicators

As previously discussed, hazard geoindicators are local geomorphologic features that can, and do, influence coastal processes and their impacts. The primary hazard geoindicators found in Nags Head include:

Topographic Geoindicators

Elevation

Nags Head has four flood zones, two of which are on the oceanfront. Each flood zone has its own development requirements for new construction as well as requirements for additions and improvements to existing structures.

VE-Zone/Special Flood Hazard Area

This zone is the closest to the water and delineates areas of the Town that will be subject to substantial wave action during a 100-year storm (areas subjected to surface waves three feet high on top of already rising waters). The VE-Zone constitutes a stretch of oceanfront from the southern corporate limits to the northern borders of the Town.

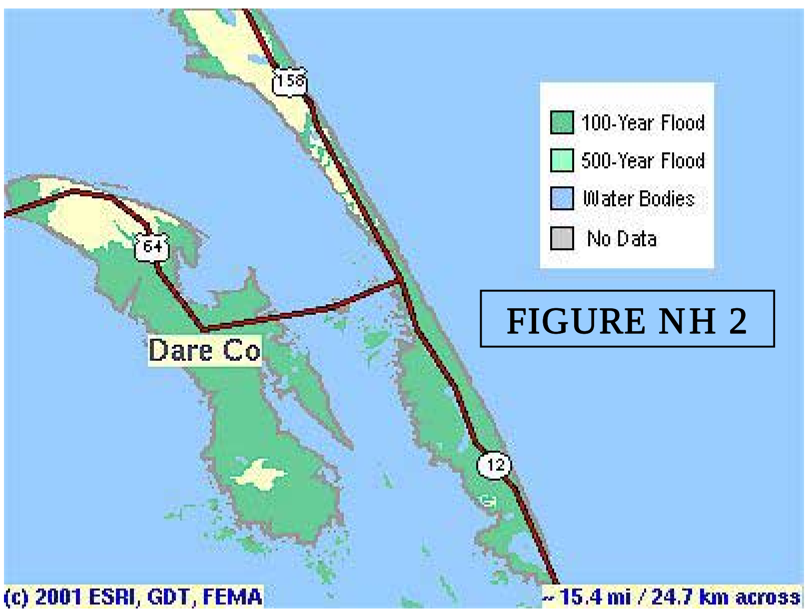


FIGURE NH 2

The VE-zone is 628 acres in size and encompasses approximately 635 developed parcels on 534 acres. The total tax value for these developed parcels was $236,887,019 as of January 1, 1997. Of the 635 structures, 293 were pre-FIRM (before adoption of the Flood Insurance Rate Maps) and built before the Town began to participate in the National Flood Insurance Program in 1978 (Nags Head, 2000).

AE-Zone/100-year Flood/ Special Flood Hazard Area

These zones delineate areas in the community that have an annual probability of one percent of being flooded (areas that will be inundated by the 100-year flood). These zones are located over almost all of the Town (Figure NH 2). Specifically, these areas include most of the land east of NC 12 and NC 1243 (although there are V-zones along the frontal dunes), much of the land between NC 12 and US 158, portions of land west of US 158 along the estuarine shoreline and Cedar and Pond islands.

The AE flood zone is 2,158 acres in area of which 1,453 acres are developed. Development within the AE flood zones is composed of approximately 1,429 structures, with a tax value of $254,964,860 as of January 1, 1997. Of these 1,429 structures, 489 structures had a tax value $166,201,000 and were built prior to the Town's participation in the National Flood Insurance Program (Nags Head, 2000).

Vegetation

Vegetation native to Nags Head includes *Spartina patens* (cord grass), *Ammophila breviligulata* (American beach grass), *Uniola paniculata* (sea oats), *Baccharis halimifolia* (eea myrtle), *Myrica cerifera* (wax myrtle), *Iva frutescens* (marsh elder), *Quercus virginiana* (live oak), *Juniperus virginiana* (red cedar), *Slex vomitoria* (yaupon) and *Spartina alterniflora* (smooth cord grass).

The most significant area of maritime forest is Nags Head Woods, one of the few remaining maritime forests in North Carolina. The Woods includes "the Fresh Pond," large stable marshlands, large vegetated and unvegetated sand dunes, a forest with ponds, wetlands, pine hummocks, bay forest and hardwood and pine forests.

To protect the Fresh Pond as a source of potable water, the Town acquired 318 acres of land west of the pond in the 1960s. Conditions of the acquisition were that the area remain as a watershed and that the area not be subject to development. In 1987, the Town revised its Zoning Ordinance and adopted a comprehensive set of zoning regulations for the protection of Nags Head

Woods. These ordinances permit primarily single-family housing and include regulations to ensure that the function and character of the maritime forest will be preserved.

In 1992, the Town, in cooperation with The Nature Conservancy (TNC), purchased 386 acres in Nags Head Woods. This tract is commonly referred to as the RTC tract, the Great Atlantic Savings Tract or the Tillett Tract. The property was acquired by the Town and The Nature Conservancy to be managed as a natural area and nature preserve.

When the property was acquired, the federal government designated the tract as part of the Coastal Barrier Resources Act, and in doing so, federal flood insurance will not be available for any development that occurs in this tract. In 1997, the Town offered Articles of Dedication to the State of North Carolina for most Town-owned property in Nags Head Woods. The offer was accepted, and this area is now dedicated in perpetuity as a nature preserve.

Nags Head Woods is included in the SED (Special Environmental District) 80 Zoning District. Of the 972 acres in the District, 303 are owned by the Town, 386 are jointly owned jointly by the Town and TNC and 27.5 are owned by TNC. As a result, approximately 73 percent of the land in Nags Head Woods is owned by the Town and TNC. Most of the land owned by the Town is managed through a cooperative agreement with the Nature Conservancy.

Shoreline Geoindicators

Shoreline geoindicators include geomorphologic features of the ocean beach, the estuarine shoreline and the offshore continental shelf. This category of geoindicators influences storm surge height, storm wave height, wave energy and storm surge ebb flow.

The Ocean Beach

Depending upon the time of year and the occurrence of recent storms and hurricanes, the beach (both wet and dry) ranges from 100 feet wide to several hundred feet wide. In areas where there has been extensive sandbagging, the sandy beach area can be non-existent during high tide.

For Nags Head there are a number of erosion rates for various sections of the beach ranging from two feet per year at Eighth Street to ten feet per year at the southern Town limits in South Nags Head

Primary/Frontal Dunes

The foredune in Nags Head ranges from nonexistent to over twenty feet in height. The dune in Nags Head is artificial, however, having been built during the Great Depression by the CCC and WPA.

Bathymetry

The bathymetry of Nags Head is illustrated in Figure NH 3 on the next page. Nags Head is classified as mesotidal which means it has a moderate tidal range. Wave energy is also moderate.

Ocean Overwash

The Halloween storm of 1991, a northeaster that followed a late season hurricane, caused an erosive wave pattern that eroded significant dune areas and caused serious ocean overwash. Subsequent storms in the winter of 1992/1993, and the summer of 1994 resulted in additional overwash as a result of dunes weakened in the Halloween storm of 1991. Some of the areas affected by the overwash drained relatively quickly, while standing water affected some areas for a week or so. The flooding is currently sporadic. The ocean overwash flooding cannot be prevented but may be controlled by a community-wide beach nourishment program.

The Estuarine/Backside Shoreline

The soundside shoreline of Nags Head is largely characterized by an eroding salt marsh, canals that were dredged to provide access to Bogue Sound and artificial fill used for development.

Inlet Geoindicators

In any major storm or hurricane, the formation of new inlets is a possibility.

While the prediction of inlet formation and their precise location is highly uncertain, particular physical features can be used to identify likely sites. Three areas within the Town have been identified as possible sites for incipient inlets.

Whalebone Junction Incipient Inlet

The area around Whalebone Junction is identified as a potential incipient inlet based on several factors including elevation, island width, canal dimensions and erosion rate.

Old Nags Head Cove Incipient Inlet

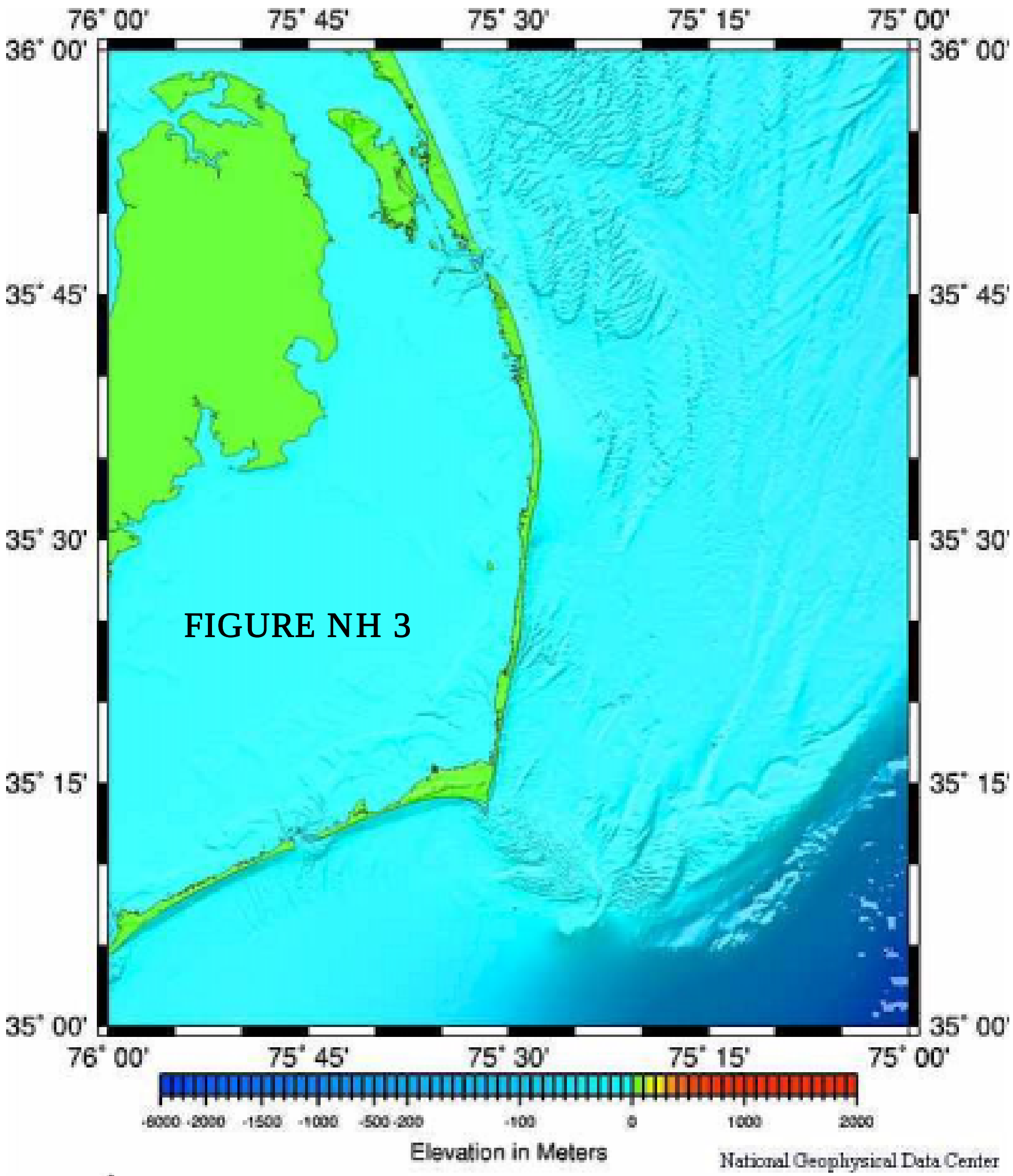
A second potential inlet site is located in the Old Nags Head Cove area where finger canals have been excavated approximately 1,000 feet perpendicular to the soundside shoreline. In this location, storm surge from the sound has a relatively unobstructed pathway across nearly half the island.

Soundside Road Incipient Inlet

A third potential inlet site is located in the Soundside Road area just south of Jockey's Ridge State Park. This area has been identified because of its relatively frequent flooding. This area experienced extreme flooding and damage during the Ash Wednesday storm of 1962.

Non-Shoreface Geoindicators

There are eleven different soil associations found within Nags Head, most of which have some type of development limitations.



Mitigation Recommendations

Nags Head is low and flat with high potential for damage from storm surge flooding, wave attack, wind damage and new inlet formation. The most widely distributed problem along the Nags Head oceanfront, in addition to erosion, are gaps in the foredune. These gaps vary in size and frequency along the length of the Nags Head oceanfront with some areas having virtually no dune protection for several hundred yards.

In addition to dune gaps, several public beach access sites have resulted in blowouts of the dune. The resultant notches in the dunes may channel storm overwash and also act as storm-surge ebb conduits.

A passage from the Nags Head 1991 CAMA Land Use Plan reads, *"Because most beach nourishment programs involve only the upper reaches of the beach, they increase its slope, and can actually in some cases increase the rate of erosion. Moreover, beach nourishment projects are typically very expensive and the results temporary and require continual nourishment. A single northeaster may eliminate much of the sand deposited under a nourishment program."*

Although the town of Nags Head has taken active steps to regulate development during the past 20 years, it has made a significant policy change regarding vulnerable and/or threatened development along its oceanfront. Historically, the Town has embraced the concept of allowing natural barrier island processes, including shoreline migration, to occur and has supported the relocation/ demolition of threatened oceanfront structures as the preferred response to buildings threatened by a migrating shoreline.

Today, however, the town supports beach nourishment as the primary way to address the problems caused by buildings that are located along a naturally migrating shoreline. This position is short-sighted, imprudent and directly contradicts the Town's previous - and correct - conclusions regarding the inadequacies of beach nourishment.

The single most important element of an effective coastal hazard mitigation strategy for the town of Nags Head is for the town to re-examine its stance on threatened oceanfront structures and to, once again, officially endorse a policy of relocation/ demolition. This will provide the Town with a successful, long-term, equitable and cost-effective way to address not only chronic erosion, but also acute storm impacts.

In addition to the need for the Town to revise its general policy regarding oceanfront erosion and development is a need for the town to addresses the vulnerability of existing and potential development, the existence of hazard geoindicators, hazardous processes and other coastal hazards.

The primary coastal hazards in Nags Head include:

- storm surge and overwash flooding
- sand deposition from overwash
- flooding from falling/standing water

Protect the integrity of the ocean beach and dune system and recognize the natural processes and dynamics of the shoreline.

The Town should strictly enforce its policy against sea walls, jetties, groins and other artificial devices designed to stabilize the ocean shoreline. Sandbags should only be allowed as temporary protection devices (no more than two years) for imminently threatened structures until they can be removed from the site or demolished.

In addition to basic economic considerations, decisions concerning the use of potential sand resources for long-term beach management in Nags Head should consider some significant parameters including the geologic framework variables controlling individual island formation and evolution, regional high-energy wave and storm climate, cumulative environmental consequences of sand mining and beach nourishment, and the specific response of each coastal segment to ongoing sea-level rise.

Implementing actions:

- Require dune crosswalks for all new oceanfront development.
- The Town should give high priority to the preservation of dunes, vegetation and topography as an important hazard mitigation component.
- Require any proposed development or redevelopment to rebuild and revegetate dunes for the purpose of creating and maintaining a continuous dune line along the oceanfront.
- Consider annually, through the Capital Improvements Program process, providing funds for the acquisition of open space in high hazard areas along the ocean shoreline.

Reduce the risks and vulnerability of structures to damage and loss from hurricanes and coastal storms in advance of such events.

The Town should actively endorse relocation, demolition and acquisition as the preferred alternatives for addressing the impacts of barrier island migration and ocean erosion upon existing structures.

Implementing actions:

- The Town should incorporate recent erosion trends and increase minimum setback distances on all oceanfront lots
- The Town should sponsor studies to determine the optimal approach for removing threatened structures from the oceanfront shoreline.
- The Town should investigate innovative programs and seek funds for mitigation measures such as relocation of threatened structures from extreme hazard areas.
- The Town should acquire oceanfront property when the opportunity arises.
- The Town should investigate mitigation programs and grants to assist property owner in the relocation of threatened structures.
- The Town should take a more proactive approach towards the condemnation of damaged structures and issue civil citations when necessary.
- Actively participate in the Federal Emergency Management Agency Community Rating System Program to develop mitigation measures to reduce or prevent flood damage from occurring in the first place.
- The Town should develop and implement a comprehensive Floodplain Management Plan and annually evaluate progress toward implementing the plan.
- The Town should continue to encourage relocation of structures that are threatened by erosion and Town Staff should actively work with homeowners and Federal Emergency Management Agency to facilitate their relocation.

Develop a set of regulations, guidelines, and development review processes that will help preserve topography, vegetation and other natural characteristics.

Existing land uses in the Woods are limited to nine residences and one former farm site. The current management system is to protect environmentally sensitive features and the water supply. The marshes may fall under protection by the Coastal Resources Commission through an AEC permit and/or by the Corps of Engineers permitting process.

Town zoning and land use regulations that are designed to prevent the filling of wetlands in certain areas should be enforced.

Development near the Fresh Pond is limited by the Zoning Ordinance and AEC regulations that restrict septic systems to one per acre within 1,200 feet of the edge of the Pond. Septic systems are prohibited within 500 feet of the edge of the Pond.

Implementing actions:

- Develop a comprehensive Corridor Vegetation Enhancement Program.
- Institute a program of land acquisition to acquire land now to protect the visual integrity of the Town.
- Develop a long-range program to place existing overhead utilities underground.

- Develop a visual enhancement program (landscaping, buffering, landscaped corridors) to protect and enhance the natural vegetation and topographical features of the Town.
- The Town should inventory open space, actively pursue grants and funding opportunities and develop and implement a plan to acquire and preserve open space throughout the Town.
- The Town should consider an incentive program to reward developers that set aside additional open space in perpetuity

Investigate more stringent building codes for high hazard areas.

Implementing actions:

- The Town should investigate the feasibility of becoming a FEMA "Project Impact" community.
- The Town should consider the applicability of requiring "V Zone" structural certification for structures in the 100-year flood zone.
- The Town should consider amendments to the Flood Ordinance that address freeboard and recognize other flood mitigation measures by FEMA and the CRS program to reduce flood loses.

Protect the physical and visual integrity of the estuarine shoreline.

Implementing actions:

- Actively pursue all sources of funding including the Capital Improvements Program to provide funds for open space and estuarine access projects.
- Develop ordinances which would exclude development detrimental to the estuarine environment.

Increase the amount of recreational open space along the ocean and estuarine shorelines and increase open space in other areas.

Implementing actions:

- Investigate the feasibility of implementing a facility fee schedule that will require payment of fees from new development that will be used for the acquisition of land for ocean and estuarine access areas.
- Submitting grant applications for shoreline access projects when the opportunities arise.
- Develop an Open Space Plan designed to identify key locations for land and easement acquisition.

Consider higher flood regulatory standards for vehicle and equipment storage areas and structures that produce, use or store volatile, flammable, explosive, toxic and or reactive materials.

Implementing actions:

- Develop a program to identify businesses and material storage areas where significant amounts of toxic or hazardous products are stored that could be subject to flooding.
- The Town should develop regulations to require fuel tanks, including LP tanks to be adequately anchored to prevent flotation or submersion in the event of flooding.

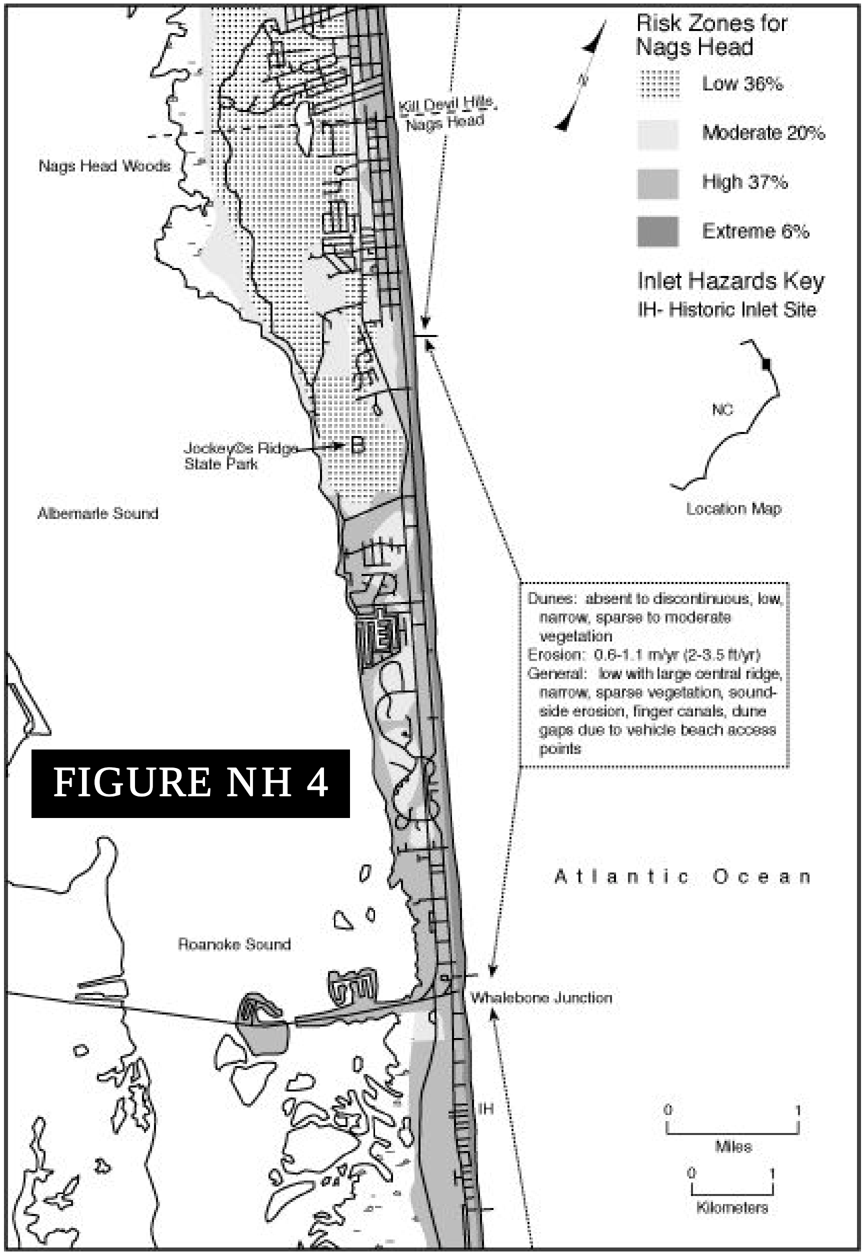


FIGURE NH 4

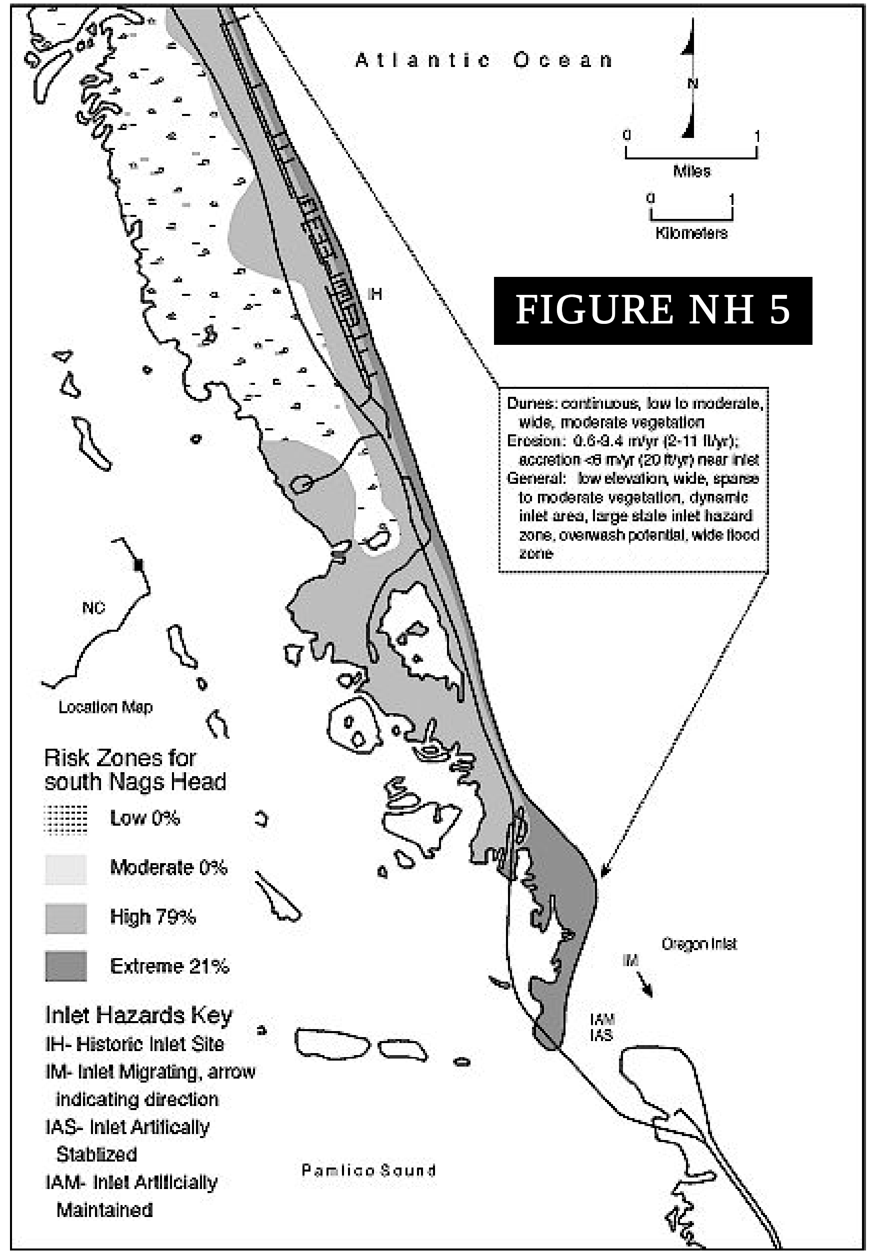


FIGURE NH 5

COMMUNITY CASE STUDY 3: NORTH TOPSAIL BEACH, NC

Community Overview

The town of North Topsail Beach makes up approximately six square miles of the northeastern end of Topsail Island, a 26-mile long northeast-southwest trending island in the North Carolina barrier island system (Figure NT1). North Topsail Beach is bordered by the New River Inlet to the northeast and the town of Surf City to the southwest.

Two bridges provide access to the island—a swing bridge in Surf City to the south and a high-rise bridge that connects North Topsail Beach to the mainland. A single main road runs parallel to the ocean along the length of the island with some shore-perpendicular roads that run from the ocean to the sound or Intracoastal Waterway. Landward of the island are areas of undifferentiated marsh, tidal flats and tidal creeks which are backed by Stump Sound at the town's southern end and the Intracoastal Waterway at the center and northern end of the town. Stump Sound is a shallow lagoonal system that ranges in width from .4 to 2.4 kilometers. The predominant littoral current at North Topsail Beach is from north to south.

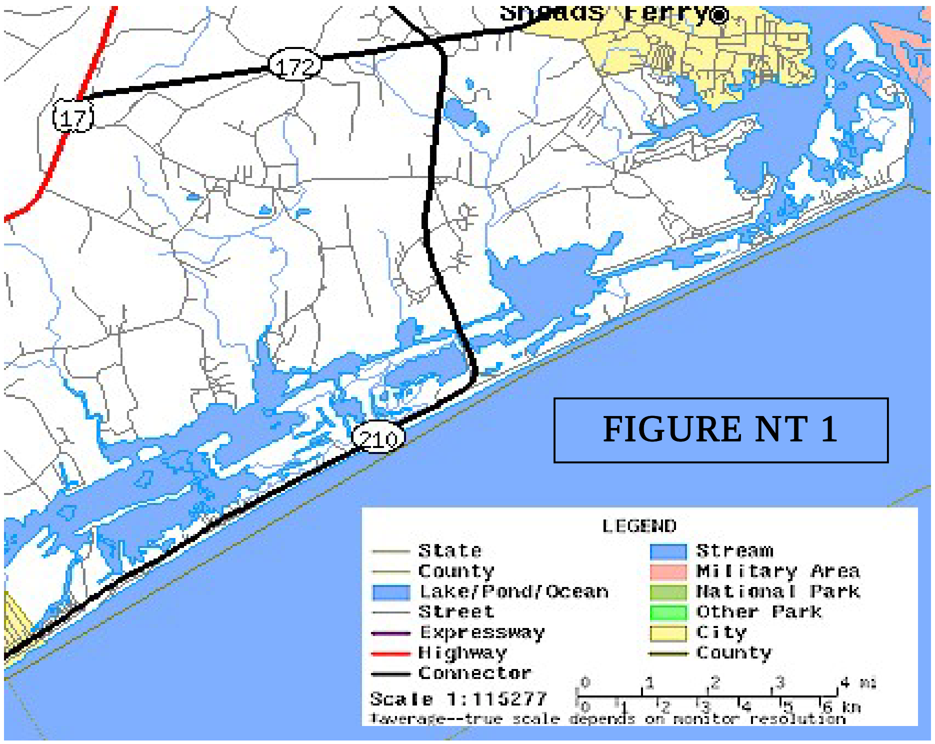


FIGURE NT 1

Development

North Topsail Beach was incorporated in 1990, and little change in the town's predominant land use patterns has occurred since this time. The town remains almost exclusively a residential community with 50% of all parcels designated for multi-family use, approximately 38% for single-family, site-built structures and the remaining 10% dedicated to mobile homes. Only two percent of the town's developed parcels are classified as nonresidential use (NTB, 1996).

The southern half of North Topsail Beach was developed before the northern half because access to the island was available via NC 210. The older, southern end of the town was developed without any land use controls and, as a result, contains a mixture of manufactured homes, site-built single-family homes, duplexes, quadraplexes and condominiums constructed at varying densities.

Much of the northern half of North Topsail Beach was developed after 1982 and is dominated by high density condominiums, duplexes and quadraplexes. Road access to this area has been, and continues to be, a significant factor that influences development north of the NC 210 bridge.

More than 120 homes were destroyed in North Topsail Beach as a result of Hurricane Bertha in July, 1996, and more than 50% of the oceanfront lots in North Topsail Beach were totally lost or rendered unbuildable as a result of erosion caused by Hurricane Fran in September, 1996.

Projected Development Trends

Although the entire town is accessible to water and sewer service, future growth will be restricted by a lack of additional pumping capacity, inadequate pressure problems, potential water quality problems and inadequate sewer system treatment capacity.

In addition, approximately half of the town is designated within a Coastal Barrier Resources System Area (CBRA) and is therefore ineligible for federal flood insurance. Private flood insurance, however, remains available in these areas.

Population

The 1999 population of North Topsail Beach was 1,139 which represents an increase of 20.3% from 1990. The population of the town is estimated to be 1,343 in 2005 (OSP, 2001). The town's peak seasonal population is approximately 12,000, with an additional 6,000 day visitors on the Fourth of July and Labor Day (NTB, 1996).

Transportation Issues

Topsail Island is served by two bridges. The Highway 210 Bridge was built in 1968 and has a design capacity of 12,000 vehicles per day in each direction. This bridge is considered to be in good condition by the NC Department of Transportation. The draw bridge at Surf City is very narrow and can only carry two-way traffic if not being crossed by a truck (at which time it is only one-way). The capacity of the Surf City bridge depends on how often it is open.

Highway 210 from the high-rise bridge south to the Pender County line is the only primary roadway within North Topsail Beach. This section of highway is seven miles long and has a typical 20 to 24-foot section width with a 60 to100-foot wide right-of-way. State Road 1568 from the high-rise bridge north has a typical section width of 18 feet and a 60-foot right-of-way. Average daily traffic on SR 1568, just north of the high-rise bridge, exceeds 3,400. Average daily traffic on Highway 210, just south of the high-rise bridge, exceeds 4,100 (NTB, 1996).

At the northern end of town, the public roadway ends and poorly-maintained private streets provide the only means of ingress and egress for a substantial number of residential units. At the southern end of town, many streets in the Ocean City and family campground remain unpaved.

The primary transportation issue facing North Topsail Beach continues to be from overwash, especially on SR 1568 near Galleon Bay. During Hurricane Fran a new inlet was formed in this area connecting Old Sound Channel and the Atlantic Ocean. This section of SR 1568 requires above average maintenance in order to remain functional due to its proximity to the Atlantic Ocean.

In less than 2 miles, SR 1568 crosses 10 small bridges that span marsh fingers, some of them with open water. Before Fran and Bertha, some of these "fingers" reached nearly to the back of the dune, effectively reducing the width of the island. During Fran and Bertha, these fingers acted like conduits for storm surge, ripping up pavement and making the road nearly impassable.

Most of the road along North Topsail Beach east to Bay Court has been relocated back from the beach a few yards toward the center of the island, but to a lower elevation.

A similar situation exists from Bay Court into the rest of the North Topsail Beach area where erosion has forced the relocation of the road all the way to Marine Drive.

Shoreline Changes

The shoreline of North Topsail Beach consists of 12 miles of Atlantic Ocean shoreline and approximately 14 miles of sound and estuarine shoreline (FEMA, 1996). Both the front and back shorelines have been dramatically altered over the past five years by several hurricanes including Bertha (1996), Fran (1996) and Floyd (1999).

Prior to Hurricanes Bertha and Fran, the town's frontal dune system north of the high-rise bridge consisted of 10 to 15-foot-high ridges. The entire frontal dune system was completely demolished by Fran, although several attempts have been made to artificially re-establish them. The frontal dune in this area now consists of discontinuous, sparsely-vegetated bulldozed dunes that range in height from 0 to 10 feet.

Before Fran, the dunes south of the high-rise bridge were discontinuous, Where they were present, the dune field consisted of a single discontinuous ridge, 13 to 23 feet wide and generally no higher than 11.5 feet. The dune is now largely absent with some discontinuous sand mounds that were established by dumping sand on the beach after Hurricane Floyd.

Geology/Morphology

The Pamlico Surface is at sea level to 34 feet in elevation and covers a narrow strip near the coast including North Topsail Beach.

The unconsolidated surface sediment is about 30 feet thick in North Topsail Beach. The Yorktown Formation of Miocene age underlies the surficial sediment unless it has been removed by erosion. This formation is about 60 feet thick near North Topsail Beach. The Castle Hayne Limestone Formation of Eocene age underlies the Yorktown Formation and the Pee Dee Formation of Cretaceous age underlies the Castle Hayne Formation.

There are eleven soil types in North Topsail Beach, each possessing some type or degree of development limitation.

Hazardous Events and Processes

North Topsail Beach is subject to hurricanes, tropical storms and extratropical cyclones. The hazardous processes of interest in North Topsail Beach are storm surge, storm overwash, storm surge ebb, erosion and wind.

Historic Storm Impacts

In 1954, Hurricane Hazel generated a storm surge of 9.5 feet and destroyed 210 of the 230 homes on the island. Hazel caused an estimated $2.5 million (in 1954 dollars) worth of property damage on Topsail Island and destroyed the Surf City drawbridge (Pilkey, 1998).

A 1987 evaluation of the island by the NC Division of Emergency Management correctly indicated that the island would be largely underwater in a category 1 or 2 hurricane, and nearly completely submerged in a category 3 hurricane.

Hurricanes Bertha and Fran in 1996 and Floyd in 1999 had profound impacts upon North Topsail Beach. In addition to the transportation impacts already described, Fran cut three deep storm-surge ebb scour channels approximately two-thirds of a mile south of the Roger's Bay Campground.

These channels scoured the road and undercut the foundations of at least two buildings. Two of the channels lined up with shore-perpendicular navigation channels cut into the marsh and the driveways that faced them. This lineation indicates that these shore-perpendicular features channeled water and enhanced scouring.

High watermark elevations for Bertha ranged from 3.9 to 6.0 feet NGVD behind the island to 9.3 feet NGVD along the Atlantic Ocean shoreline. High watermark elevations for Fran ranged from 8.1 feet NGVD behind the island to 11.5 feet NGVD along the Atlantic Ocean shoreline (FEMA, 1996).

Hazard Geoindicators

As previously discussed, hazard geoindicators are local geomorphologic features that can, and do, influence coastal processes. The primary hazard geoindicators found in North Topsail Beach include:

Topographic Geoindicators

Elevation

The majority of North Topsail Beach lies at an elevation of ten feet above mean sea level or less with an average elevation of 9 feet. Because of its low elevation, the entire community lies within the 100-year floodplain (Figure NT 2).

All oceanfront properties and property bordering the New River are at least partially classified as being in an NFIP V-zone. All sound-side properties adjacent to the V-zone are classified as being in the A-zone. Only two small pockets of land are classified as B-zone properties - a sand dune located on Permuda Island and an elevated rise on Cedar Bush Cut Island at the northern end of North Topsail Beach where the Intracoastal Waterway joins the New River. Both sites are unsuitable for development and have been classified as conservation zones by the town. Except for the dunes, slopes throughout the town are generally below 12 percent (NTB, 1996).

Vegetation

Vegetation type and density varies along the town's length with the area near the New River Inlet almost completely void of any vegetation. Areas of intact maritime forest are located north of New River Inlet Road and on the landward-side of Highway210 south of the high-rise bridge. The remainder of the town is vegetated by sparse shrub and grass (Pilkey, 1998). Vegetation native to North Topsail Beach includes *Spartina patens* (cord grass), *Ammophila breviligulata* (American beach grass), *Uniola paniculata* (sea oats), *Baccharis halimifolia* (eea myrtle), *Myrica cerifera* (wax myrtle), *Iva frutescens* (marsh elder), *Quercus virginiana* (live oak), *Juniperus virginiana* (red cedar), *Slex vomitoria* (yaupon) and *Spartina alterniflora* (smooth cord grass).

FIGURE NT 2

Shoreline Geoindicators

Shoreline geoindicators include geomorphologic features of the ocean beach, the estuarine shoreline and the offshore continental shelf. This category of geoindicators influences storm surge height, storm wave height, wave energy and storm surge ebb flow.

The Ocean Beach

The average, long-term erosion rate in North Topsail Beach ranges from 2 to 5 feet/year north of the high-rise bridge to about 2 feet/year south of the high-rise bridge (Pilkey, 1998). The beach currently ranges in width from 10 to 120 meters from the dune line to the high water line.

Primary/Frontal Dunes

The frontal dune south of the high-rise bridge consists of a discontinuous, unvegetated sand dike that ranges in height from 0 to 15 feet. This artificial dune line was constructed in September, 1999 using overwash sand deposited by Hurricane Floyd. Sand was removed from streets and parking lots and stockpiled in the parking lot of the old Ocean City Pier. This sand was screened and returned to the beach by dump truck.

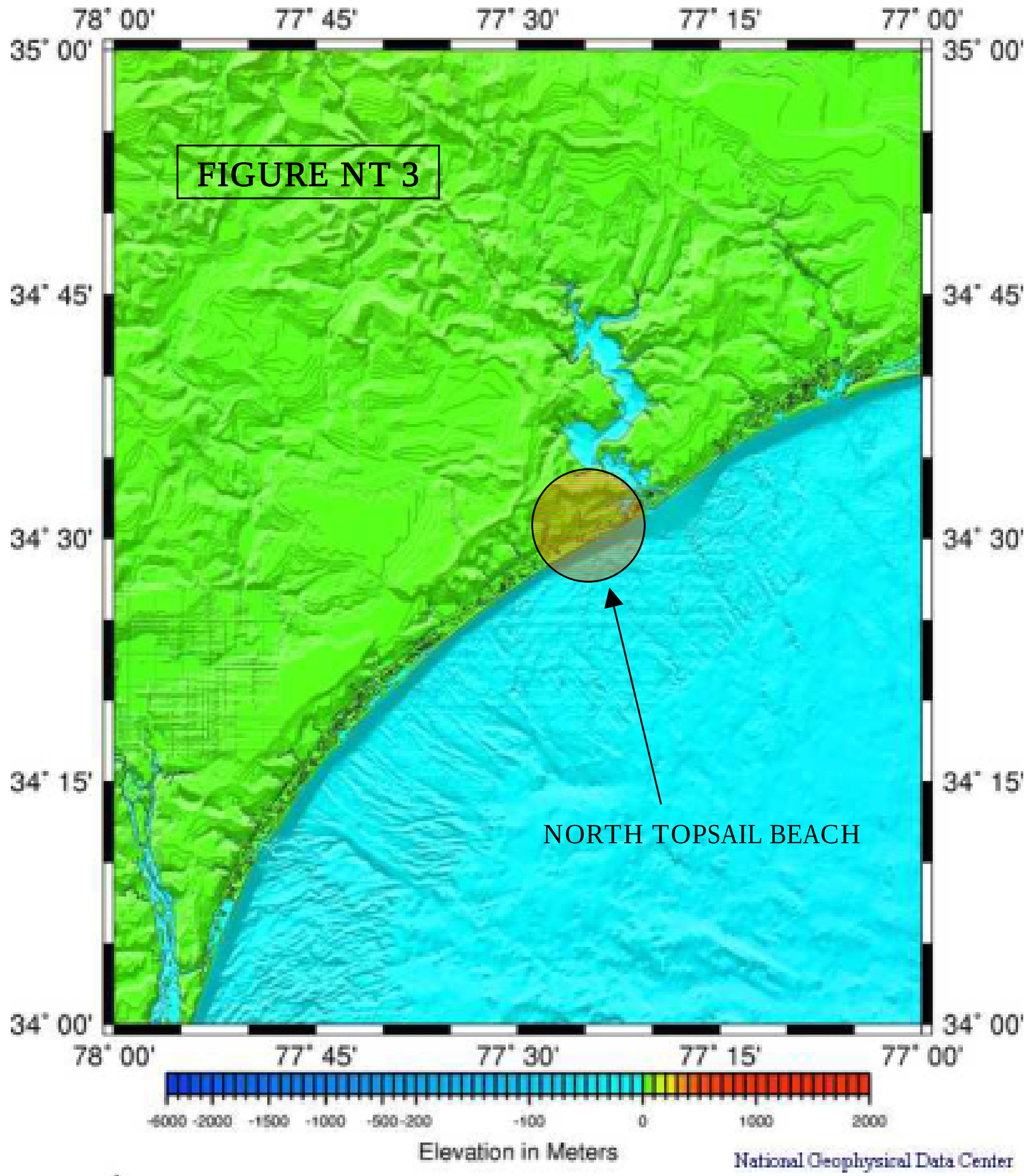
North of the high-rise bridge, the dune line varies considerably. There is no dune just north of the NC 210-SR 1568 intersection, at the Onslow County PBA, immediately south of the Villa Capriani Resort and north of the Topsail Reef condominium complex. A well-vegetated, discontinuous dune line 6 to 10 feet in height exists just south of the Onslow Beach PBA, just north of Salty's Pier and between the St. Regis Resort and Topsail Reef condominiums.

Bathymetry

The bathymetry of North Topsail Beach is illustrated in Figure NT 3 on the next page. North Topsail Beach is located on the western edge of Onslow Bay, a large coastal embayment that stretches from Cape Lookout, NC to Cape Fear, NC. Onslow Bay is a high energy (1m average wave height) microtidal system typified by an abidance of rock outcrops of Tertiary to Quaternary.

The Onslow Bay shelf is sediment-starved and the introduction of new sediment to Onslow Bay is negligible due to: 1) no fluvial input (coarse sediments are trapped in the upper estuarine system) and 2) minimal sediment exchange between adjacent shelf. Much of the offshore area is dominated by Oligocene limestones and siltstones mantled with a patchy, thin veneer of interbedded muddy sands and shell units (Cleary, 2001).

The dominant direction of wave approach is from the northeast during the winter months, and from the southeast during the summer Typically, storm waves approach from the northeast, but the area is also subject to episodic storm wave events from the east and south during the passage of



tropical and extra tropical cyclones. Hindcast wave data (WIS studies) indicate a mean wave height of 1.1 meters, with a 7 second period. The dominant direction of wave approach is from the southeast. The net longshore drift is to the southwest.

Storm Surge

The maximum estimated 100-year storm stillwater surge elevation for North Topsail Beach is 12.4 feet (including wave setup of 2.1 feet). In 1996, Hurricane Fran produced a storm surge of 12 feet in North Topsail Beach. The maximum 100-year wave crest elevation is 19 feet (FEMA, 1996).

Storm Overwash

North Topsail Beach experienced extensive storm overwash during Hurricanes Bertha, Fran and Floyd. Significant overwash occurred along most of the length of the town during Floyd. In areas where development did not interfere with the washover process, sediment covered SR 1568 and Highway 210 and was deposited into the backside marsh. The only areas that did not experience any measurable overwash include:

1) The Surf City Campground
2) A small stretch just north of the NTB Fire Station
3) A small stretch just north of the Rogers Bay Campground
4) The residential area extending from just south of the high-rise bridge south to just north of the St. Moritz resort
5) A small stretch just north of the Onslow County PBA

In general, those areas that did not experience overwash were fronted by a relatively continuous, well-vegetated dune line in excess of 6 feet in elevation.

The Estuarine/Backside Shoreline

The soundside shoreline of North Topsail Beach is largely characterized by an eroding salt marsh and marsh canals and channels that were dredged to provide access to Stump Sound and the Intracoastal Waterway.

Inlet Geoindicators

North Topsail Beach has several inlet hazard areas including the New River Inlet, areas where past inlet activity has occurred and areas where future inlet activity may be expected.

New River Inlet

New River Inlet (Figure NT 4) separates North Topsail Beach to the southwest from military-owned Onslow Beach to the northeast. The inlet has generally moved to the southwest, although it periodically has moved northeast.

Historical charts indicate that the inlet has migrated within a 2-kilometer zone since 1856. The migration-zone width for the inlet is controlled by the ancestral channel of the New River, the majority of which is located on the Onslow Beach shoulder.

In recent history, the width of the inlet has fluctuated from a minimum of 66 meters in 1938 to a maximum of 382 meters in 1987. Over the past 60 years, the average width of the inlet has been 225 meters. Maintenance dredging of the inlet began in 1963. Prior to this time, inlet migration rates averaged 14.5 meters per year. Since 1963, the migration rate has decreased to 3.8 meters per year (Cleary, 1999).

The US Army Corps of Engineers currently maintains the New River Inlet channel which helps to stabilize the northeastern tip of North Topsail Beach. This area, however, is extremely low and much of it is a state-designated inlet hazard zone.

Further, oceanfront erosion trends are related to the changing shape of the ebb-tidal delta, which in turn is governed by the orientation of the ebb channel. During the period 1962 to 1982, for example, 115 meters of accretion were recorded along a 1-kilometer stretch of oceanfront on North Topsail Beach. Since 1990, however, this area of North Topsail Beach has been dominated by erosion (Cleary, 1999)

Future Inlets

A potential inlet site in North Topsail Beach is located perpendicular to Tradewinds Drive at Galleon Bay (Figure NT 5). A channel formed in this location during Hurricane Fran that connected Old Sound Channel to the Atlantic Ocean. There is currently a bridge here.

Ten other potential inlet or swash sites are located at the small bridges along SR 1568 north of the high-rise bridge. These areas are highly susceptible to inlet formation during even moderate storms (Figure NT 6).

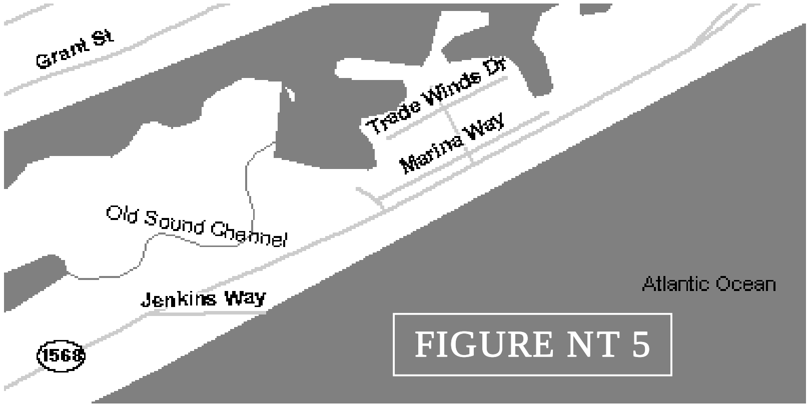
Non-Shoreface Geoindicators

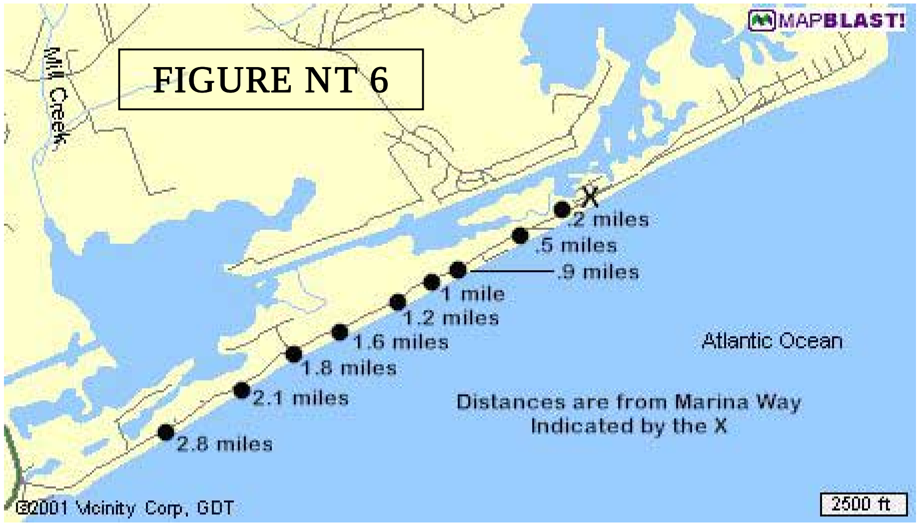
There are eleven different soil associations found within North Topsail Beach, all of which have some type of development limitations.

Mitigation Recommendations

Hazard mitigation recommendations for North Topsail Beach are extremely limited due to low elevation, the narrowness of the island, the community's proximity to New River Inlet, the lack of adequate sediment resources and recent storm impacts. From a geologic perspective, North Topsail Beach is the most vulnerable coastal community in North Carolina and the only mitigation recommendation that can be made with any degree of confidence is for the town to develop and implement a short- and long-term retreat/relocation plan.

In light of the fact that such a recommendation is likely to be disregarded by the community, the following hazard mitigation recommendations are being presented in an effort to minimize storm impacts to existing development.





Preserve the integrity of the ocean, beach and dune system and recognize the natural processes and dynamics of the shoreline.

Even though North Topsail Beach is located in a sediment-poor region of the NC coast and little sand is available to establish and maintain a broad beach for storm protection purposes, the town is currently investigating the feasibility of a federal shoreline protection project. Should this study conclude that a federal project is not feasible in North Topsail Beach, the town should consider the following alternatives.

General Implementing Actions:

- The Town should strictly enforce the state's policy against sea walls, jetties, groins and other artificial devices designed to stabilize the ocean shoreline.
- Allow sandbags only as temporary protection devices for no more than two years and only for imminently threatened structures until they can be removed from the site or demolished.
- Construct and maintain a continuous frontal/primary dune field along the entire oceanfront of Atlantic Beach using compatible sand from an off-island source.
- Increase the volume of any existing frontal/ primary dune field using compatible sand from an off-island source.
- Establish dune vegetation using native species.
- Require any proposed development or redevelopment to rebuild and revegetate dunes for the purpose of creating and maintaining a continuous dune line along the oceanfront.
- Plug all dune gaps and prevent the creation of new gaps.
- Construct dune crossovers, both pedestrians and vehicular, where access to the beach is desired.
- Allow sand, deposited by storm surge and storm overwash, to remain in place.

Reduce the risks and vulnerability of structures to damage and loss from hurricanes and coastal storms in advance of such events.

The Town should actively endorse relocation, demolition and acquisition as the preferred alternatives for addressing the impacts of barrier island migration and ocean erosion upon existing structures.

Implementing actions:

- The Town should incorporate recent erosion trends and increase minimum setback distances on all oceanfront lots
- Increase building density and building size restrictions on all lots.
- The Town should prevent development within 500 feet of existing overwash or swash channels.
- The Town should establish a program to fund the purchase of lots containing "imminently threatened" structures and lots with substantially damaged structures. All publicly-owned lots should remain as permanent open space.
- The Town should develop a retreat/ relocation/evacuation plan for the entire community
- The Town should investigate mitigation programs and grants to assist property owner in the relocation/ demolition of threatened structures.
- The Town should sponsor studies to determine the optimal approach for removing threatened structures from the oceanfront shoreline.
- The Town should take a more proactive approach towards the condemnation of damaged structures and issue civil citations when necessary.

Protect the physical and visual integrity of the estuarine shoreline.

Implementing actions:

- Actively pursue all sources of funding including the Capital Improvements Program to provide funds for open space and estuarine access projects.
- Develop ordinances which would exclude development detrimental to the estuarine environment.

COMMUNITY CASE STUDY 4: CAROLINA BEACH, NC

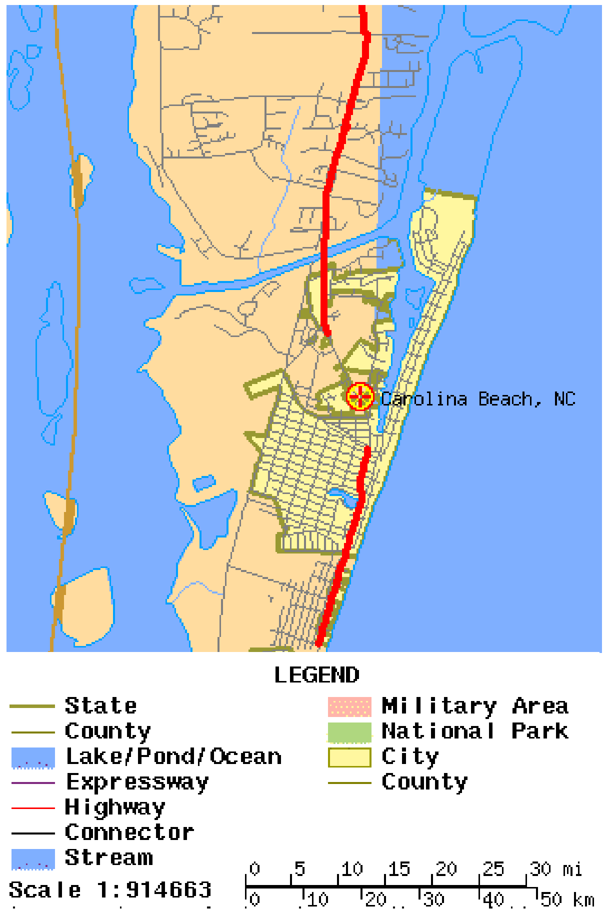
Community Overview

Carolina Beach, located at 34:02:06 N 077:53:38 W, comprises a low-lying, narrow spit of sand backed by a narrow marsh that is attached to the mainland near Atlantic Avenue. Carolina Beach correlates to two natural divisions in its shoreline. From Carolina Beach Inlet to the vicinity of the Carolina Beach City Hall, the coast is that of a barrier island backed by a narrow sound. The area from the City Hall through Wilmington Beach is attached to the mainland without the intervening sound, has partial forest cover and elevations above the 100-year storm surge flood level (Pilkey, 1987).

Carolina Beach is bordered to the north by Carolina Beach Inlet and by the town of Kure Beach to the south. The Carolina Beach shoreline has a north-northeast, south-southwest alignment. The predominance of wave energy components in Carolina Beach is from the northeast quadrant which produces a dominant southward littoral transport. Coquina rock fragments, originating in the vicinity of Fort Fisher to the south, have been found along the Carolina Beach shoreline which indicates some littoral transport to the north (US Army, 1962).

Development

Carolina Beach began to develop toward the end of the nineteenth century. In the early 1880s, the only means of transportation to the beach was by way of poorly paved shell



roads. In 1886, citizens organized the New Hanover Transit Corporation that erected a pier just south of Snow's Cut on the Cape Fear River. From here, passengers arriving by steamer from Wilmington were transported to the beach by a narrow gauge railroad. By 1890, several large hotels and numerous make-shift cottages dotted the beach.

Development prior to 1925 was relatively slow. In 1954, Hurricane Hazel destroyed the first brick hotel - built in 1924 – at the corner of Ocean Blvd. and South Carolina Avenue.

Approximately 45% of all housing units in Carolina Beach are either single family residences or duplexes, 53% are multi-family units and 2% are mobile homes.

Over the last 30 years, Carolina Beach has evolved from a predominantly vacant landscape to a predominantly developed community. Rapid and uncontrolled development in Carolina Beach has resulted in narrowed dunes, filled marshlands, finger canals and removal of most native vegetation (Pilkey, 1998). During this time, significant areas of Bogue Sound were bulkheaded and filled, and a significant amount of development took place on small lots unsuitable for septic systems.

During the 1980s, construction in Carolina Beach was dominated by multi-family units. Since that time, single-family units have become the leading type of dwelling unit constructed (Carolina Beach, 1996). The 1995 construction value for all residential dwelling units was $2,644,721. Today, Carolina Beach is a mixture of commercial and residential uses that are primarily seasonal and resort oriented.

Projected Development Trends

During the next 20 years, public land use changes in Carolina Beach may include redevelopment of the "circle" and construction of a central sewer treatment and collection system. These changes will likely increase property values, promote the conversion of existing mobile home parks to permanent residential dwelling units, increase traffic congestion and allow for the dispersion of commercial development.

Population

The permanent population of Carolina Beach, as of July, 1999, was 5,139. This represents a 41.6% increase since 1990 and a 209% increase since 1970 (OSP, 2001). The permanent population of Carolina Beach is projected to grow another 20% to 6,160 by 2010. The estimated peak overnight population of Carolina Beach is estimated to exceed 17,000 and the estimated peak day population is estimated to exceed 40,000 (Carolina Beach, 1997).

Transportation Issues

Highway and street system improvements are the most important transportation infrastructure issues in Carolina Beach (Carolina Beach, 1997).

Shoreline Changes

From 1857 to 1938, the average annual recession of the mean high water shoreline in Carolina Beach was 2.3 feet. The average annual recession of the shoreline from 1940 to 1955 was 14.7 feet per year. From 1952 to 1977, the erosion rate along the northern portion of Carolina Beach averaged 40.2 feet per year (Cleary, 1977).

Early in 1955 a discontinuous dune ridge was constructed along the shore from Carolina Beach south to Fort Fisher. Sand was obtained by dredging 252,000 cubic yards of sand from Myrtle Sound near the channel. Additional sand was bulldozed from the foreshore zone to the dune line. The dune ridge was broken by numerous drainage channels, buildings and the Carolina Beach boardwalk.

In June 1955, a rubble concrete groin was completed at the foot of Hamlet Street, about 300 feet south of the boardwalk. The groin was 100 feet long and 12 feet wide at a crest elevation of 8 feet above mean low water. Both the groin and constructed dune ridge were completely demolished in the summer of 1955 by three hurricanes (Connie, Diane and Ione) and the entire project lasted only 7 months (Cleary, 1977).

During September and October 1956, approximately 200,000 cubic yards of material was pumped on the beach. In November 1956, 12 groins were constructed between Wilmington Beach and 16th Avenue in Carolina Beach.

In 1962, the US Army Corps of Engineers described the erosion of the beach immediately south of the Carolina Beach Inlet as "substantial" and authorized a shoreline protection project that would eventually include 14,000 feet of beach in Carolina Beach. The project commenced in 1965 when 3,500,000 cubic yards of material was pumped onto the beach from Myrtle Grove Sound and the Intracoastal Waterway (US Army, 1962). Additional sand was pumped on the beach in 1967, 1970 and 1971. A 1,100 foot granite boulder seawall was built in 1970 and extended an additional 950 feet in 1973 (Cleary, 1977).

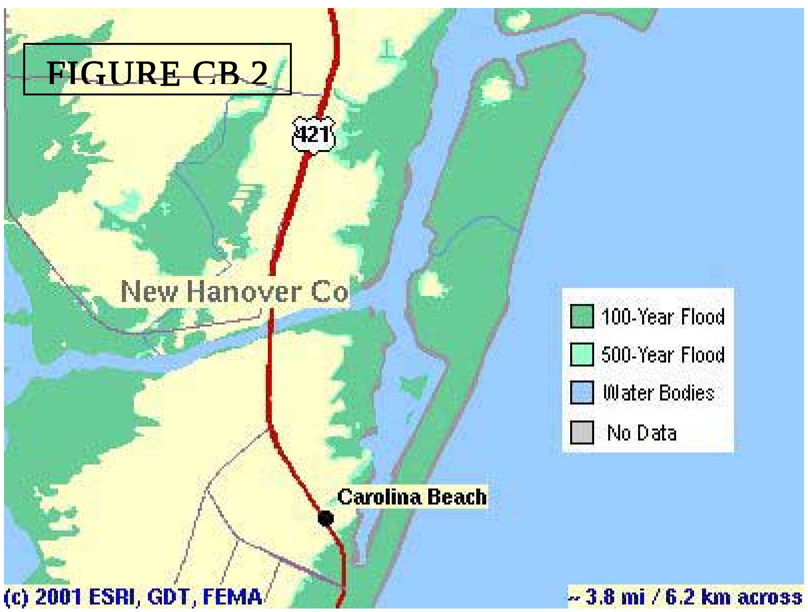
The current average annual long-term erosion rate in Carolina Beach is difficult to determine due to the ongoing beach nourishment project.

Geology/Morphology

The Pamlico formation is a low, nearly level terrace at an elevation less than 25 feet above present sea level. The materials in this formation are fine sandy loams, clays, sands and some gravel. Deposits of recent age overlie the Pamlico formation. These include tidal marsh, beach sands and dunes. In marsh areas, the soil consists largely of accumulations of peaty matter. The thickness of the deposits varies from 15 to 25 feet.

Hazardous Events and Processes

Carolina Beach is subject to hurricanes, tropical storms and extratropical cyclones and has been directly impacted by at least 10 major hurricanes in the past 60 years (four in the past five years). The hazardous processes of interest in Carolina Beach include storm surge, wave action, storm overwash and wind.



Historic Storm Impacts

Many hurricanes have pounded this section of the North Carolina coast, but it was not until the 1890s that storm accounts began to make mention of this area. Carolina Beach was struck by a severe storm in 1893 and in 1898, the Navy lookout station was destroyed by heavy storm surf. A year later, numerous resort cottages were washed away or damaged.

The most destructive storm of the first half of this century was probably that of August 1, 1944 when Carolina Beach incurred some of the heaviest damage of the entire North Carolina coast. Two piers were destroyed, trees were blown down and the water rose high enough to flood second-story levels. In 1954, Hurricane Hazel destroyed over 370 buildings, damaged over 700 others and produced a high-water mark of 13 feet above mean sea level along the Carolina Beach oceanfront. Less than a year later, Hurricanes Connie and Diane caused additional damage, and in 1959 Hurricane Grace flooded the town (Pilkey, 1978).

Carolina Beach experienced a relatively tranquil period until 1996 when Hurricanes Bertha and Fran impacted the town within a few months of each other. Fran produced a stillwater level of 11.1 feet while Bertha produced a storm surge of about 5 feet (NOAA, 2001). The last major storm to impact Carolina Beach was Hurricane Floyd in 1999 which caused a storm tide (water height above National Geodetic Vertical Datum or sea level) of 10.3 feet on nearby Masonboro Island. (NOAA, 2001).

Hazard Geoindicators

As previously discussed, hazard geoindicators are local geomorphologic features that can, and do, influence coastal processes. The primary hazard geoindicators found in Carolina Beach include:

Topographic Geoindicators

Elevation

The average elevation of Carolina Beach is five feet above sea level (US Census, 2001). Because of its low elevation, a significant portion of the town is located within the FEMA 100-year flood zone (See Figure CB 2), and most of the town will be inundated by a category 3 hurricane (Carolina Beach, 1996).

Vegetation

Vegetation native to Carolina Beach includes *Spartina patens* (cord grass), *Ammophila breviligulata* (American beach grass), *Uniola paniculata* (sea oats), *Baccharis halimifolia* (eea myrtle), *Myrica cerifera* (wax myrtle), *Iva frutescens* (marsh elder), *Quercus virginiana* (live oak), *Juniperus virginiana* (red cedar), *Slex vomitoria* (yaupon) and *Spartina alterniflora* (smooth cord grass).

Shoreline Geoindicators

Shoreline geoindicators include geomorphologic features of the ocean beach, the estuarine shoreline and the offshore continental shelf. This category of geoindicators influences storm surge height, storm wave height, wave energy and storm surge ebb flow.

The Ocean Beach

Since 1955, at least 20 sand pumpings have been necessary to hold the shoreline in place, and the beach in front of the stone revetment at the north end of Carolina Beach has experienced rapid loss of nourishment sand. The average, long-term erosion rate in Carolina Beach is approximately 2 feet/year (Pilkey, 1998).

Primary/Frontal Dunes

Dunes are discontinuous, low and narrow with sparse vegetation along much of the oceanfront shoreline. Dune heights range from 0 to approximately 15 feet.

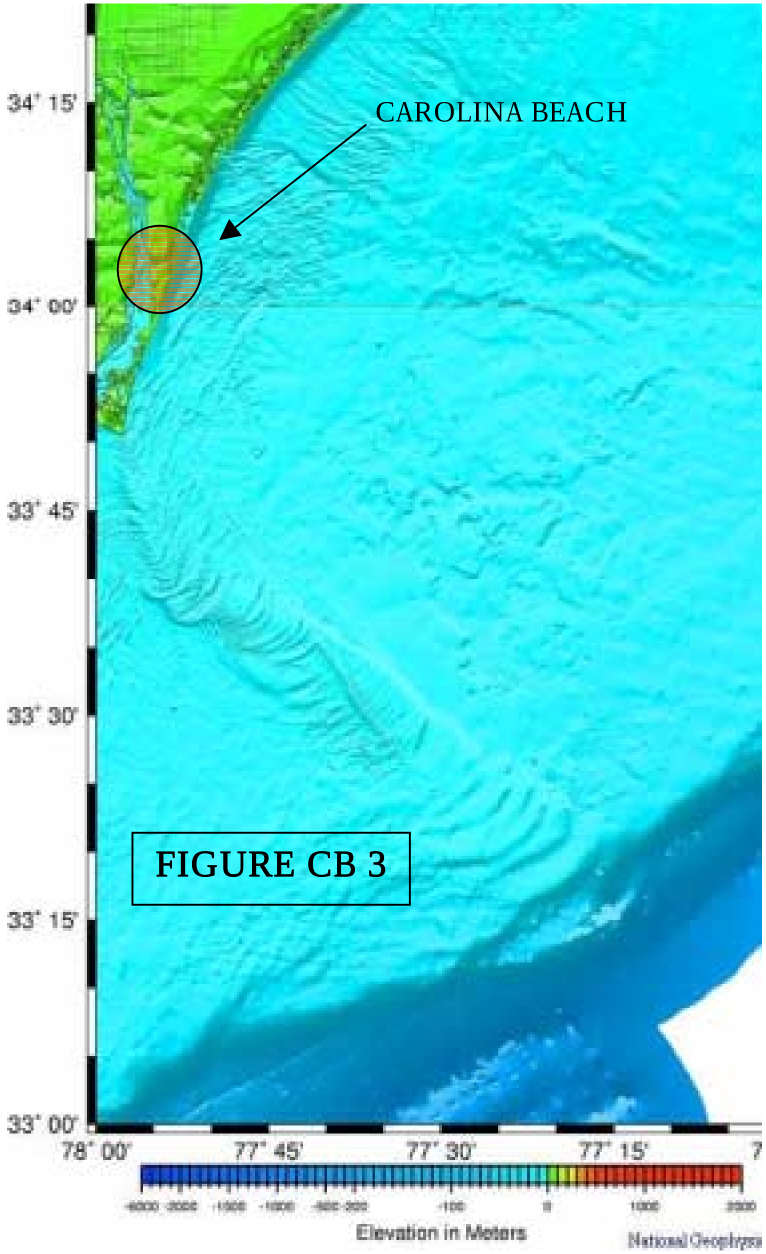


FIGURE CB 3

Bathymetry

The bathymetry of Carolina Beach is illustrated in Figure CB 3 on the next page. Carolina Beach has a normal tidal range of approximately 4.2 feet and is classified as mesotidal. Wave energy is moderate.

The shoreface off of Carolina Beach is sediment starved and dominated by hard rock outcrops called hardbottoms. Several hardbottom morphologies occur depending on the lithology of the units outcropping on this shoreface. Three rock types exist on the subaerial headland shoreface: Pleistocene Coquina, Plio-Pleistocene Limestone, and Oligocene Dolosilt.

Hardbottoms are either high relief (>0.5m) or low relief (<0.5m). High relief hardbottoms consist of scarps and overhangs and are typically encrusted with organisms such as algae, mollusks, corals and bryozoans. Lower relief hardbottoms are intermittently covered with sand sheets and have minor amounts of encrusting organisms. Low relief hardbottoms are the dominant type on this shoreface.

Hardbottoms contribute sediment to the shoreface sediment budget through biological and mechanical erosion. Organisms and storm and wave processes serve as the agents that degrade the rock surfaces and cause sediment to be produced. Hardbottoms are an important part of this shoreface system, as they affect the morphology of the shoreface and neighboring beaches (UNC, 2001).

The Backside Shoreline

Due to its unique geological setting, the non-ocean shoreline of Carolina Beach fronts several different types of waterbodies. West of Dow Road the town borders the Cape Fear River. Northeast of town is Snows Cut, an artificial waterway created to link the Cape Fear River to Myrtle Sound. Myrtle Sound extends south from Carolina Beach Inlet to just north of Carl Winner Street.

Myrtle Sound is a shallow body of water, about 6 miles long and a few hundred feet to about 1 mile wide, that lies between the mainland and the barrier beach adjacent to and north of Carolina Beach (Figure CB 4) (US Army, 1962). The shoreline of Myrtle Sound is characterized by an eroding marsh.

Inlet Geoindicators

Carolina Beach Inlet separates the barrier-spit portion of Carolina Beach to the southwest from undeveloped Masonboro Island to the northeast. The inlet connects the Atlantic Ocean to Myrtle Sound and was artificially opened by local interests in 1952 at the site of Sugarloaf Inlet, a short-lived inlet of the late 19th century.

The width of the inlet has varied widely over the years from a minimum of 117 meters in

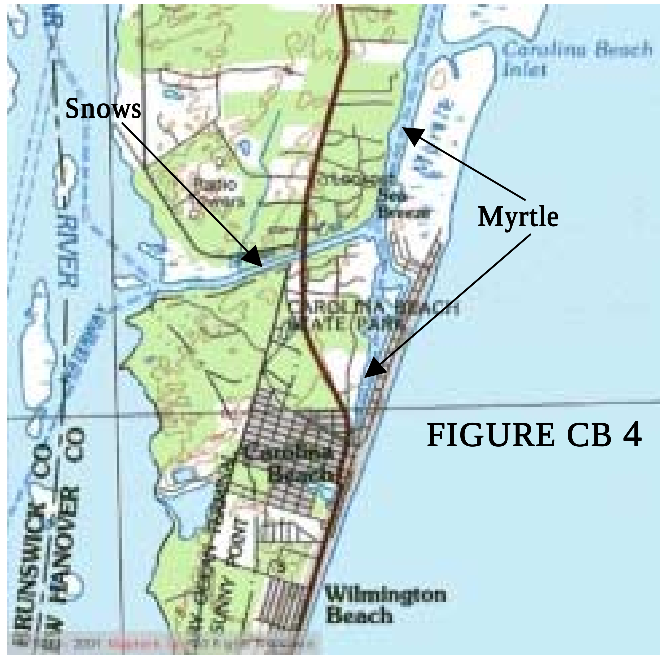


FIGURE CB 4

1966 to a maximum of 427 meters in 1985. The width of the inlet in 1999 was 202 meters. Fluctuations in width are related to deflection of the ebb channel within the throat of the inlet and the consequent erosion of the Masonboro Island shoulder.

After the opening of the inlet, both Carolina Beach and Masonboro Island began to erode at an increasing rate. The chronic erosion along Carolina Beach was attributed to the reduced rate of sand bypassing at Carolina Beach Inlet as the ebb-tidal delta expanded and the system attempted to reach a balance with local conditions (Cleary, 1999).

Non-Shoreface Geoindicators

There are eleven different soil associations found within Carolina Beach, most of which have some type of development limitations.

Mitigation Recommendations

Due to its geological formation, a significant portion of Carolina Beach is categorized as low to moderate risk. The town does, however, contain areas of high and extreme risk. Figure CB 5 provides a detailed illustration of risk and hazard geoindicators in Carolina Beach. Figure CB6 provides a more generalized overview of risk. Areas of extreme risk, indicated in Figure CB6, extend several blocks westward from the immediate open ocean shoreline.

Because of the ongoing beach nourishment project, shoreline migration is not considered a priority issue at this time. Even though the beach is artificially maintained, oceanfront properties and low areas are still subject to storm surge, flooding and storm overwash.

While erosion problems associated with a migrating shoreline in Carolina Beach are not addressed in this section, it does not mean that erosion will not become an issue once nourishment ceases, nor does it mean that erosion should not be considered during the development process.

A priority hazard mitigation recommendation for Carolina Beach is to establish more stringent community-wide building restrictions in the event that the federal beach nourishment project is ever discontinued. With development restrictions in place, the town can significantly reduce the amount of development that may eventually become vulnerable to coastal storm processes.

Even though the open ocean beach in Carolina Beach is artificially maintained, development immediately adjacent to the shoreline remains at extreme risk from a major hurricane as well as from extra tropical cyclonic activity.

Protect the integrity of the ocean beach and dune system and recognize the natural processes and dynamics of the shoreline.

The Town should strictly enforce state policy against sea walls, jetties, groins and other artificial devices designed to stabilize the ocean shoreline. Sandbags should only be allowed as temporary protection devices (no more than two years) for imminently threatened structures until they can be removed or demolished.

In addition to basic economic considerations, decisions concerning the use of potential sand resources for long-term beach management in Carolina Beach

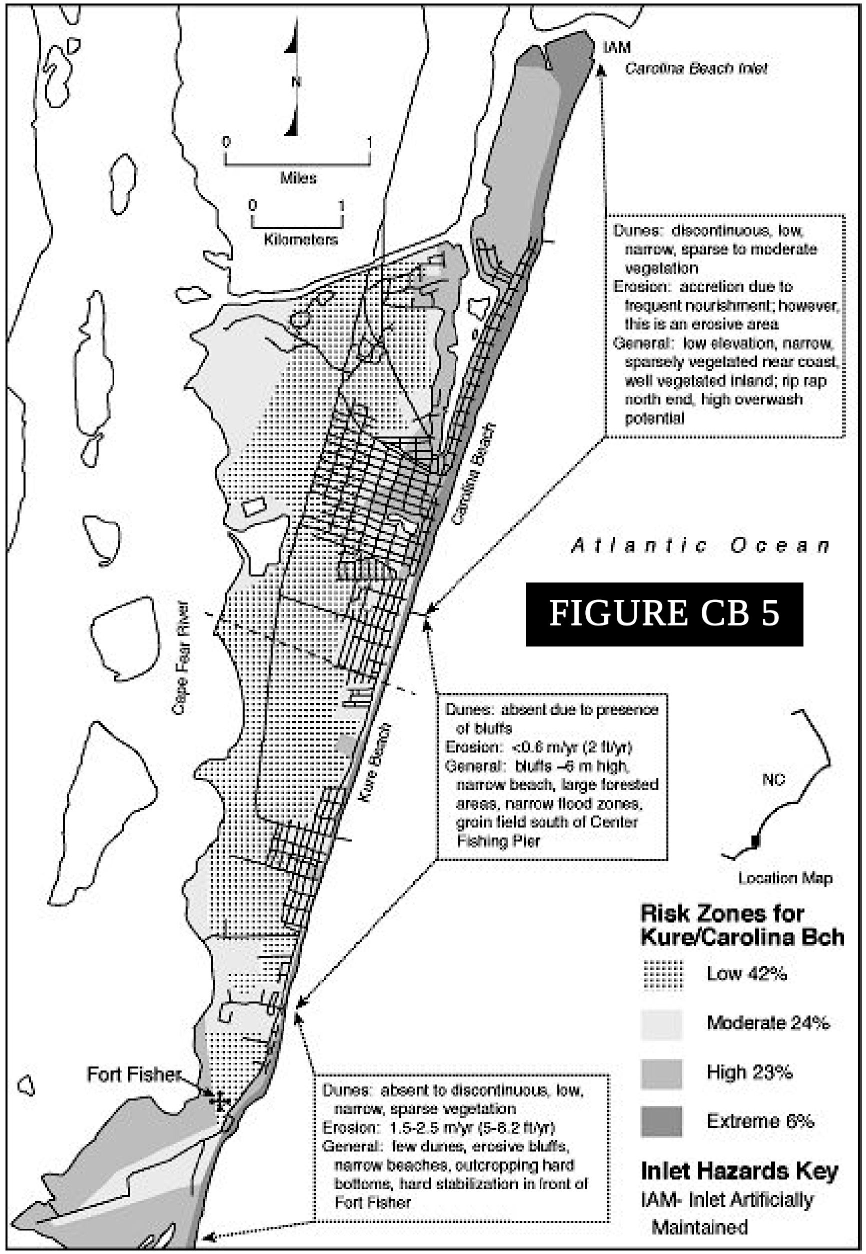


FIGURE CB 5

should consider the following parameters: geologic framework variables controlling individual island formation and evolution; regional wave and storm climate; cumulative environmental consequences of sand mining and beach nourishment; and the specific response of each segment of the community to sea-level rise.

Implementing actions:

- Require dune crosswalks for all new oceanfront development.
- The Town should give high priority to the preservation of dunes, vegetation and topography as an important hazard mitigation component.
- Require any proposed development or redevelopment to rebuild and revegetate dunes for the purpose of creating and maintaining a continuous dune line along the oceanfront.
- Consider annually, through the Capital Improvements Program process, providing funds for the acquisition of

open space in high hazard areas along the ocean shoreline.

Reduce the risks and vulnerability of structures to damage and loss from hurricanes and coastal storms in advance of such events.

The Town should actively endorse relocation, demolition and acquisition as the preferred alternatives for addressing the impacts of barrier island migration and ocean erosion upon existing structures. Implementing actions:

- The Town should sponsor studies to determine the optimal approach for removing threatened structures from the oceanfront shoreline.
- The Town should investigate innovative programs and seek funds for mitigation measures such as relocation of threatened structures from extreme hazard areas.
- The Town should acquire oceanfront property when the opportunity arises.
- The Town should investigate mitigation programs and grants to assist property owner in the relocation of threatened structures.
- The Town should take a more proactive approach towards the condemnation of damaged structures and issue civil citations when necessary.
- Actively participate in the Federal Emergency Management Agency Community Rating System Program to develop mitigation measures to reduce or prevent flood damage from occurring in the first place.
- The Town should develop and implement a comprehensive Floodplain Management Plan and annually evaluate progress toward implementing the plan.
- The Town should continue to encourage relocation of structures that are threatened by erosion and Town Staff should actively work with homeowners and Federal Emergency Management Agency to facilitate their relocation.
- Investigate the possibility of developing a long-term retreat/relocation/evacuation plan for all oceanfront structures in the event that beach nourishment is discontinued
- Prevent development densities from increasing

Develop a set of regulations, guidelines, and development review processes that will help preserve topography, vegetation and other natural characteristics.

General Implementing Actions:

- Allow sand, deposited by storm surge and storm overwash, to remain in place.
- Develop a comprehensive Corridor Vegetation Enhancement Program.
- Institute a program of land acquisition to acquire land now to protect the visual integrity of the Town.
- Develop a long-range program to place existing overhead utilities underground.
- Develop a visual enhancement program (landscaping, buffering, landscaped corridors) to protect and enhance the natural vegetation and topographical features of the Town.
- Inventory open space, actively pursue grants and funding opportunities and develop and implement a plan to acquire and preserve open space throughout the Town.
- Consider an incentive program to reward developers that set aside additional open space in perpetuity

Investigate more stringent building codes for high hazard areas.

Implementing actions:

- The Town should investigate the feasibility of becoming a FEMA “Project Impact” community.
- The Town should consider the applicability of requiring “V Zone” structural certification for all structures.

Protect the physical and visual integrity of the shoreline.

Implementing actions:

- Actively pursue all sources of funding including a Capital Improvements Program to provide funds for open space and estuarine access projects.
- Develop ordinances which would exclude development detrimental to the estuarine environment.

Increase the amount of recreational open space along the ocean and estuarine shorelines and increase open space in other areas.

Implementing actions:

- Investigate the feasibility of implementing a facility fee schedule that will require payment of fees from new development that will be used for the acquisition of land for ocean and estuarine access areas.
- Submitting grant applications for shoreline access projects when the opportunities arise.
- Develop an Open Space Plan designed to identify key locations for land and easement acquisition.

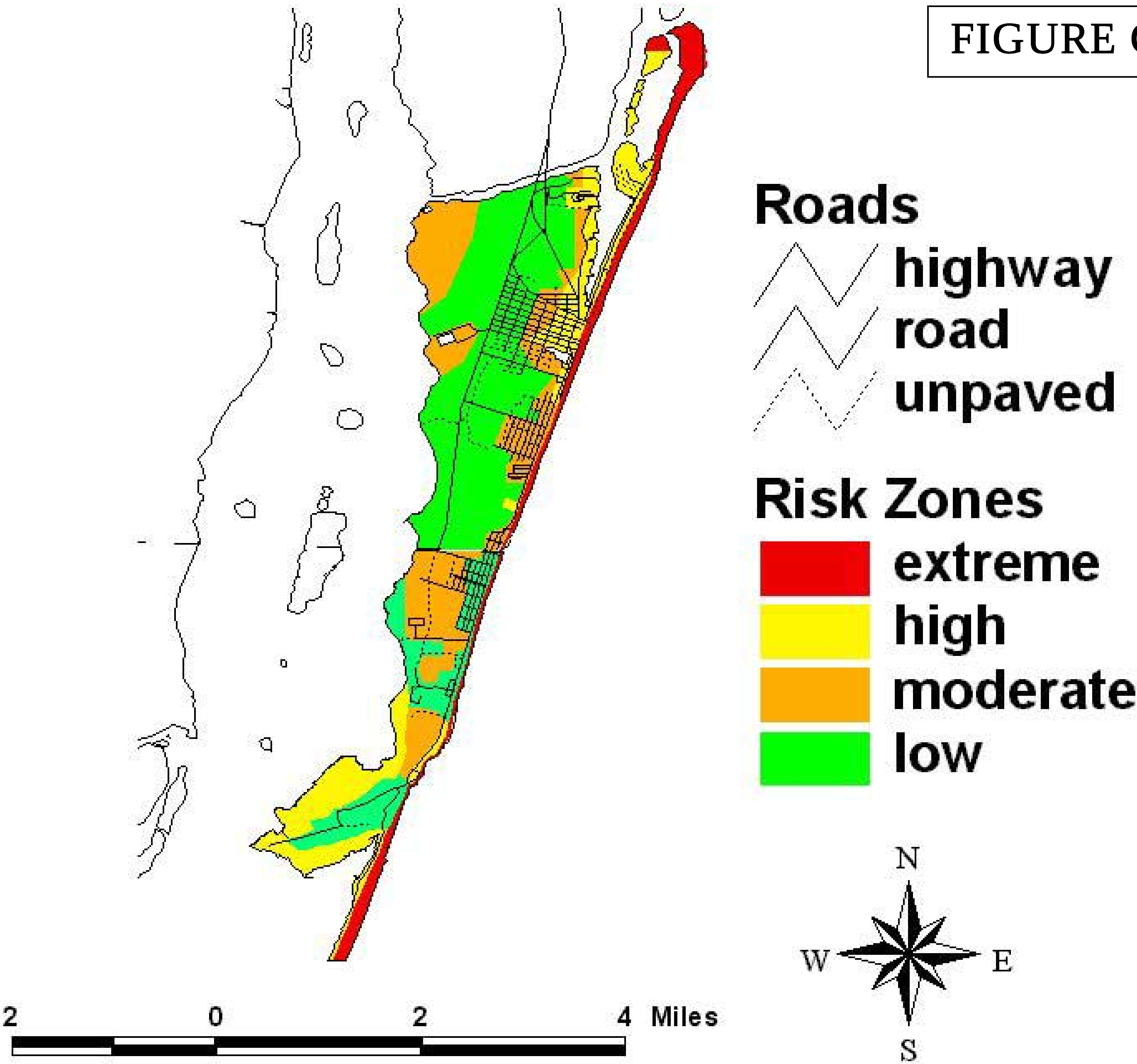
Consider higher flood regulatory standards for vehicle and equipment storage areas and structures that produce, use or store volatile, flammable, explosive, toxic and or reactive materials.

Implementing actions:

- Develop a program to identify businesses and material storage areas where significant amounts of toxic or hazardous products are stored that could be subject to flooding.
- The Town should develop regulations to require fuel tanks, including LP tanks to be adequately anchored to prevent flotation or submersion in the event of flooding.

Carolina Beach

FIGURE CB 6



COMMUNITY CASE STUDY 5: OCEAN ISLE BEACH, NC

Community Overview

The town of Ocean Isle Beach was incorporated in 1959 and is comprised of a 6-mile long southwest-northeast trending barrier island and a 1,300-acre extraterritorial area on the mainland in Brunswick County, NC (Figure OIB 1). The barrier island encompasses approximately 1,950 acres, of which 920 are undevelopable marsh, beaches and surface water (OIB, 1997). Ocean Isle Beach is positioned 33.89 degrees north of the equator and 78.43 degrees west of the prime meridian. The predominant littoral current along Ocean Isle Beach is from west to east (Stanczuk, 1975).

The island is separated from the mainland by salt marsh and the Intracoastal Waterway. Vehicular access to the island is achieved via NC Highway 904 along a causeway and high-rise bridge
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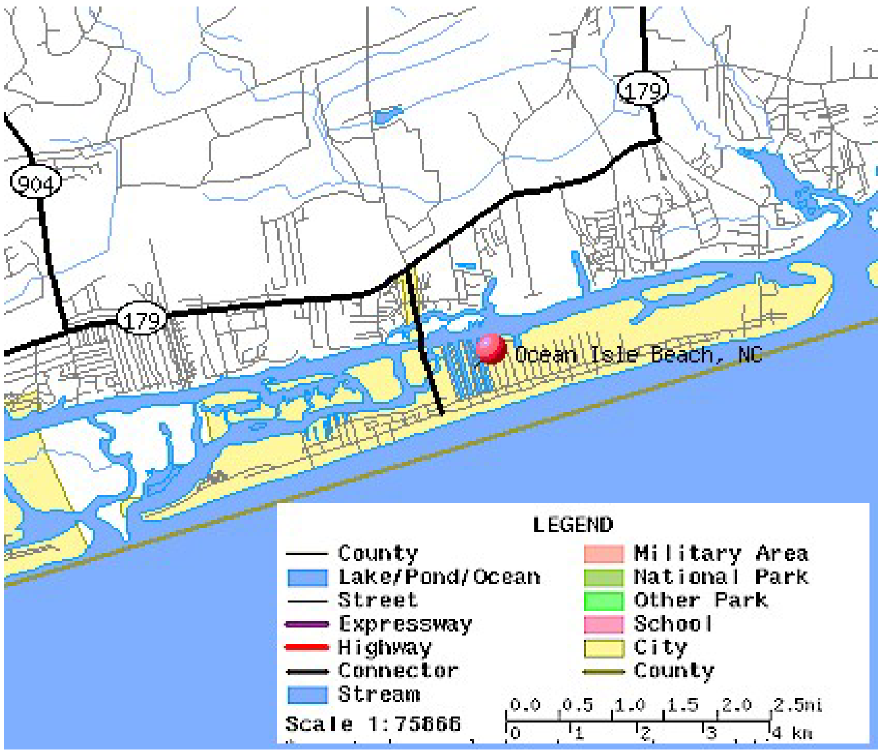


Development

The predominant land use in Ocean Isle Beach consists of single-family houses. This pattern has changed little since 1990 (OIB, 1997). An average of 57.4 new housing units/year was constructed in OIB between 1990 and 1997, and this rate is expected to continue through 2007. The town's 1996 assessed property valuation was #388,828,494 (OIB, 1997).

Projected Development Trends

As of 1997, only 50% of the town's platted residential lots had been developed and several large tracts had not yet been subdivided. Over the next ten years, large single-family residences (over 5,000 ft^2) are expected to be built east of Beaufort Street which will yield 6 dwellings per acre.

Development west of Beaufort Street is anticipated to consist of medium density (8 units/acre) multi-family residential units in planned unit developments (PUD). One proposed PUD is expected to add 700 units on 85.5 acres of land over the next 25 years. Water and sewer services will be provided to all new lots (OIB, 1997).

Population

The current permanent population of OIB (excluding the ETA) is approximately 767 with a seasonal population of 22,000 (OIB, 2001).

Shoreline Changes

The shoreline of Ocean Isle Beach was nourished seven times between 1974 and 1984. In early 2001, the Ocean Isle Beach commenced a 3.25

mile-long beach nourishment project extending from Shallotte Blvd. west to a point near Duneside Drive. This project will place approximately 1,952,600.00 yds^3 of sand on the beach at an estimated cost of $8.2 million (Wrenn, 2001).

The project design profile, which will be maintained over the 50-year life of the project, calls for the beach to be increased in width by approximately 125 feet in areas that have a full construction profile. The construction profile on both ends of the project will be tapered back to the existing profile in the transition areas. Maintenance fill, which will add an additional 50 feet of width to the beach, will be used to compensate for the loss of fill material into the near shore area, as well as through erosion, until the next maintenance renourishment. After the initial construction, the beach is scheduled for periodic renourishment every 3 years for the 50-year life of the project.

Sand is being dredged from the Shallotte Inlet channel borrow site on the east end of the island. Sand is being pumped onto the beach where bulldozers form the desired beach profile.

The total cost over the 50-year life of the renourishment project is estimated to be $45.9 million. Project costs are shared between federal, state and local sources. The federal share is 65% and the non-federal share is 35%. Non-federal funding is cost shared between the state and local sponsors. The Town of Ocean Isle Beach is paying its share of the project from a Beach Erosion and Renourishment Fund that was established in 1989. This fund consists of contributions from a tourism accommodation tax fund and three cents of the town's property tax rate (OIB, 2001).

Geology/Morphology

The Pamlico formation is a low, nearly level terrace at an elevation less than 25 feet above present sea level. The materials in this formation are fine sandy loams, clays, sands and some gravel. Deposits of recent age overlie the Pamlico formation. These include tidal marsh, beach sands and dunes. In marsh areas, the soil consists largely of accumulations of peaty matter. The thickness of the deposits varies from 15 to 25 feet.

Hazardous Events/Processes

Ocean Isle Beach is subject to hurricanes, tropical storms and extratropical cyclones. The hazardous processes of interest in Ocean Isle Beach are storm surge, storm overwash, erosion and inlet migration.

In 1999, Hurricane Floyd caused significant impacts to Ocean Isle Beach. East of Greensboro Street, the first line of natural stable vegetation (the building setback reference feature) was displaced landward up to 70 feet in many locations. East of Goldsboro Street, several structures sustained structural damage and virtually all wooden walkovers were damaged. After Floyd, every oceanfront structure east of Goldsboro Street was located seaward of the first line of natural stable vegetation. In addition to structural damages, First Street, between Winston-Salem Street and Durham Street, was undermined and washed-out.

Hurricanes Hazel in 1954, Hugo in 1989 and Fran in 1996 also had significant impacts on Ocean Isle Beach. Hazel completely overwashed Ocean Isle Beach, destroying 33 of 35 homes and washing the remaining 2 homes nearly a mile away. Hurricane Hugo, despite making landfall almost 200 miles south of Ocean Isle Beach, destroyed several homes. Fran stranded many homes out in the surf zone (Pilkey, 1996).

Hazard Geoindicators

As previously discussed, hazard geoindicators are local geomorphologic features that can, and do, influence coastal processes. The primary hazard geoindicators found in Ocean Isle Beach include:

Topographic Geoindicators

Elevation

The average elevation of Ocean Isle Beach is between six and eight feet above sea level. Because of its low elevation, almost all of Ocean Isle Beach is located within the 100-year flood zone (Figure OIB 2).

V-zone Base Flood Elevation ranges from 15 to 23 feet while the AE-zone Base Flood Elevation ranges from 13 to 17 feet. NFIP V-zone areas include land bordering Shallotte and Tubb's Inlets, along the oceanfront and immediate backside of the island. AE-zones include much of the land between the primary dune crest and the backside of the island.

Vegetation

Along the back edge of the island is a broad area of maritime forest/shrub thicket that extends from Second Street to the eastern end of the island. Vegetation native to Ocean Isle Beach includes *Spartina patens* (cord grass), *Ammophila breviligulata* (American beach grass), *Uniola paniculata* (sea oats), *Baccharis halimifolia* (eea myrtle), *Myrica cerifera* (wax myrtle), *Iva frutescens* (marsh elder), *Quercus virginiana* (live oak), *Juniperus virginiana* (red cedar), *Slex vomitoria* (yaupon) and *Spartina alterniflora* (smooth cord grass).

Shoreline Geoindicators

Shoreline geoindicators include geomorphologic features of the ocean beach, the estuarine shoreline and the offshore continental shelf. This category of geoindicators influences storm surge height, storm wave height, wave energy and storm surge ebb flow.

The Ocean Beach

The average, long-term erosion rate in Ocean Isle Beach is approximately 2 feet/year except along the eastern-most end where erosion rates are listed at 5 feet/year (NC DCM, 1992). The ocean beach in Ocean Isle Beach has been, and currently is being, artificially maintained through a federal beach nourishment project.

Prior to nourishment, the dry subaerial beach ranged in width from 0 to 50 feet, measured from the high water line to an existing reference feature (i.e. frontal dune toe, first line of stable vegetation or structure). Immediately after Hurricane Floyd, the width of the dry beach from Greensboro Street east to Shallotte Inlet measured less than 20 feet (Coburn, 1999). The dry beach, immediately post nourishment, is expected to average 125 feet in width.

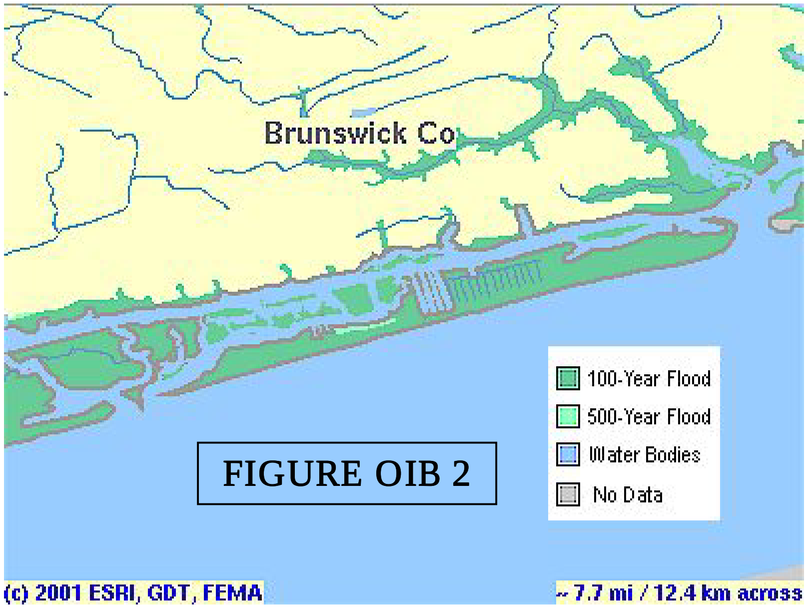


FIGURE OIB 2

Primary/Frontal Dunes

Prior to Hurricane Floyd, Ocean Isle Beach was fronted by a heterogeneous mix of dune types. East of Southport Street, the frontal dune line consisted primarily of bulldozed, unvegetated, scarped sand piles. Exposed sandbags were observed in several locations between Raleigh and Highpoint Streets. A 140-foot long vegetated frontal dune was located immediately in front of the Winds Oceanfront Inn at 310 East First Street. At this location, sandbags had been covered with sand and dune vegetation had been established. As a result, additional sand had been trapped and dunes had built up.

West of Southport Street to the pier, the frontal dunes were scarped but well-vegetated with little signs of bulldozing. Frontal dune heights averaged 8-10 feet.

West of the pier, the frontal dune averaged just under 10 feet in height, was well-vegetated and showed little signs of erosion.

Bathymetry

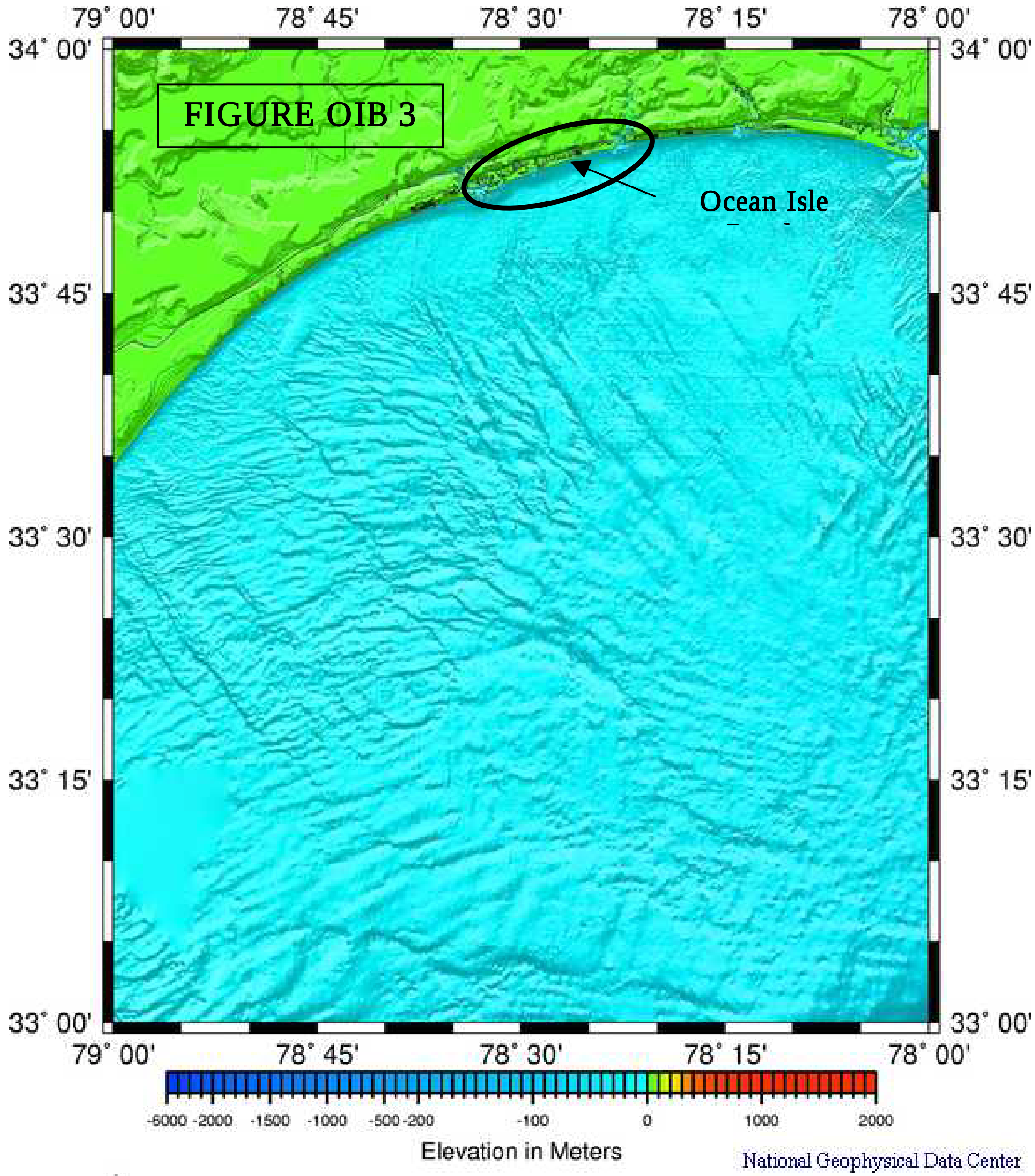
Ocean Isle Beach fronts Long Bay, the shelf embayment from south of Cape Fear to Cape Romain, South Carolina. Long Bay is sediment starved and dominated by outcropping Cretaceous and Tertiary units (Cleary, 2001). The bathymetry off Ocean Isle Beach is illustrated in Figure OIB 3. Ocean Isle Beach is classified as mesotidal which means it has a moderate tidal range. Wave energy is also moderate.

The Estuarine/Backside Shoreline

The soundside shoreline of Ocean Isle Beach is largely characterized by an eroding salt marsh and finger canals that were dredged to provide access to Tubbs and Shallotte Inlets. Coastal wetlands, as defined by the NC Coastal Area Management Act, are generally located in the northern portions of the island adjacent to the Intracoastal Waterway. The most substantial area of wetlands is located in the northwest portion of the island between the Intracoastal Waterway and Old Sound Creek. Another wetlands area is the land adjacent to the finger canals leading to the waterway (OIB, 1997).

Inlet Geoindicators

Ocean Isle Beach has two inlet hazard areas: Tubbs Inlet to the west and Shallotte Inlet to



the East. Tubbs Inlet is an unstable inlet that has demonstrated erratic movements in the past and may do so in the future. Prior to 1970, Tubbs Inlet was migrating to the west. During this period of time, the primary feeder channel behind the Ocean Isle shoulder of Tubbs Inlet was infilled, and it no longer was the primary feeder channel.

At some time between 1970 and 1983, Jenks Creek was dredged, opening it to the Intracoastal Waterway. The dredging and opening of Jenks Creek allowed a greater volume of water to be exchanged between the ocean and estuary. This infilling, or the reduction in the primary eastern feeder channel along with the dredging of Jenks Creek on the western side of the inlet, is likely to be among the variable factors causing the present easterly migration of Tubbs Inlet (Clearly, 1996).

Non-Shoreface Geoindicators

Four soil types are found within Ocean Isle Beach: Bohicket, Carteret, Corolla and Newhan. Bohicket and Carteret soils drain very poorly and are subject to severe flooding and ponding of water. These soils are found primarily in the marshes and tidal flats. Corolla and Newhan soils are found mainly along the oceanfront Corolla is prone to flooding and ponding of water while Newhan has severe limitations for septic system use (OIB maintains a central sewer system and does not permit septic systems on the island).

In 1994, the central dune ridge of the island was largely removed by bulldozing just west of Highway 904. The ridge was the only portion of the island above the 100-year flood level.

Mitigation Recommendations

Prior to the 2001 beach nourishment project, the eastern third of Ocean Isle Beach had been experiencing extensive erosion. Because of the ongoing federal beach nourishment project, shoreline migration on Ocean Isle Beach is not currently considered a priority issue. However, even though the beach is being artificially maintained, oceanfront properties and low areas are still subject to storm surge, flooding and storm overwash.

While erosion problems associated with a migrating shoreline in Ocean Isle Beach are not addressed in this section, it does not mean that erosion may not become an issue, nor does it mean that erosion should not be considered during the development process.

In light of the ongoing federal nourishment project, the priority hazard mitigation recommendation for Ocean Isle Beach is to establish and enforce stringent community-wide building restrictions that prevent any increase in development. This is, in fact, a NC state requirement (15A NCAC 02G .0107 - Special Beach Erosion Control Requirements) for all beach erosion control or hurricane protection projects in which the state participates by action of the department. According to 15A NCAC 02G .0107:

> Before the start of project construction, the sponsoring local government(s) will establish land-use controls to conserve protective dunes and to insure that the damage potential is not significantly increased by further development. Such land use controls must meet or exceed all requirements of the state guidelines for Areas of Environmental Concern (15A NCAC 7H) and be consistent with the approved local land use plan prepared under the provisions of the state guidelines for Land Use Planning (15A NCAC 7B).

With the required development restrictions in place, Ocean Isle Beach can be certain that additional development will not eventually become vulnerable to coastal storm processes when the federal beach nourishment project ends.

However, even though the open ocean beach in Ocean Isle Beach is artificially maintained, development immediately adjacent to the shoreline remains at extreme risk from a major hurricane as well as from extra tropical cyclonic activity.

Protect the integrity of the ocean beach and dune system and recognize the natural processes and dynamics of the shoreline.

OIB should strictly enforce state policy against sea walls, jetties, groins and other artificial devices designed to stabilize the ocean shoreline. Sandbags should only be allowed as temporary protection devices (no more than two years) for imminently threatened structures until they can be removed or demolished.

In addition to basic economic considerations, decisions concerning the use of potential sand resources for long-term beach management in OIB, the town should consider the following parameters: geologic framework variables controlling individual island formation and evolution; regional wave and storm climate; cumulative environmental consequences of sand mining and beach nourishment; and the specific response of each segment of the community to sea-level rise.

Implementing actions:

- Require dune crosswalks for all oceanfront development.
- The Town should give high priority to the preservation of dunes, native vegetation and topography as an important hazard mitigation component.
- Require any proposed development or redevelopment to rebuild and revegetate dunes for the purpose of creating and maintaining a continuous dune line along the oceanfront.
- Consider annually, through the town's Capital Improvements Program process, providing funds for the acquisition of open space in high and extreme hazard areas along the ocean shoreline.

Reduce the risks and vulnerability of structures to damage and loss from hurricanes and coastal storms in advance of such events.

OIB should actively endorse relocation, demolition and acquisition as the preferred alternatives for addressing the impacts of barrier island migration and ocean erosion upon existing structures.

Implementing actions:

- OIB should sponsor studies to determine the optimal approach for removing threatened structures from the oceanfront shoreline.
- OIB should investigate innovative programs and seek funds for mitigation measures such as relocation of threatened structures from extreme hazard areas.
- OIB should encourage relocation of structures that are threatened by erosion and Town Staff should actively work with homeowners and Federal Emergency Management Agency to facilitate their relocation.
- OIB should acquire oceanfront property when the opportunity arises.
- OIB should investigate mitigation programs and grants to assist property owner in the relocation of threatened structures.
- OIB should take a more proactive approach towards the condemnation of damaged structures and issue civil citations when necessary.
- OIB should actively participate in the Federal Emergency Management Agency Community Rating System Program to develop mitigation measures to reduce or prevent flood damage from occurring in the first place.
- OIB should develop and implement a comprehensive Floodplain Management Plan and annually evaluate progress toward implementing the plan.
- OIB should Investigate the feasibility of developing a long-term retreat/ relocation/ evacuation plan for all oceanfront structures in the event that beach nourishment is discontinued

Develop a set of regulations, guidelines, and development review processes that will help preserve topography, vegetation and other natural characteristics.

General Implementing Actions:

- OIB should allow sand, deposited by storm surge and overwash, to remain in place.
- OIB should develop a comprehensive Corridor Vegetation Enhancement Program.
- OIB should institute a program of land acquisition to acquire land now to protect the visual integrity of the Town.
- OIB should develop a visual enhancement program (landscaping, buffering, landscaped corridors) to protect and enhance the natural vegetation and topographical features of the Town.

- OIB should inventory open space, actively pursue grants and funding opportunities and develop and implement a plan to acquire and preserve open space throughout the Town.
- OIB should consider an incentive program to reward developers that set aside additional open space in perpetuity

Investigate more stringent building codes for high hazard areas.

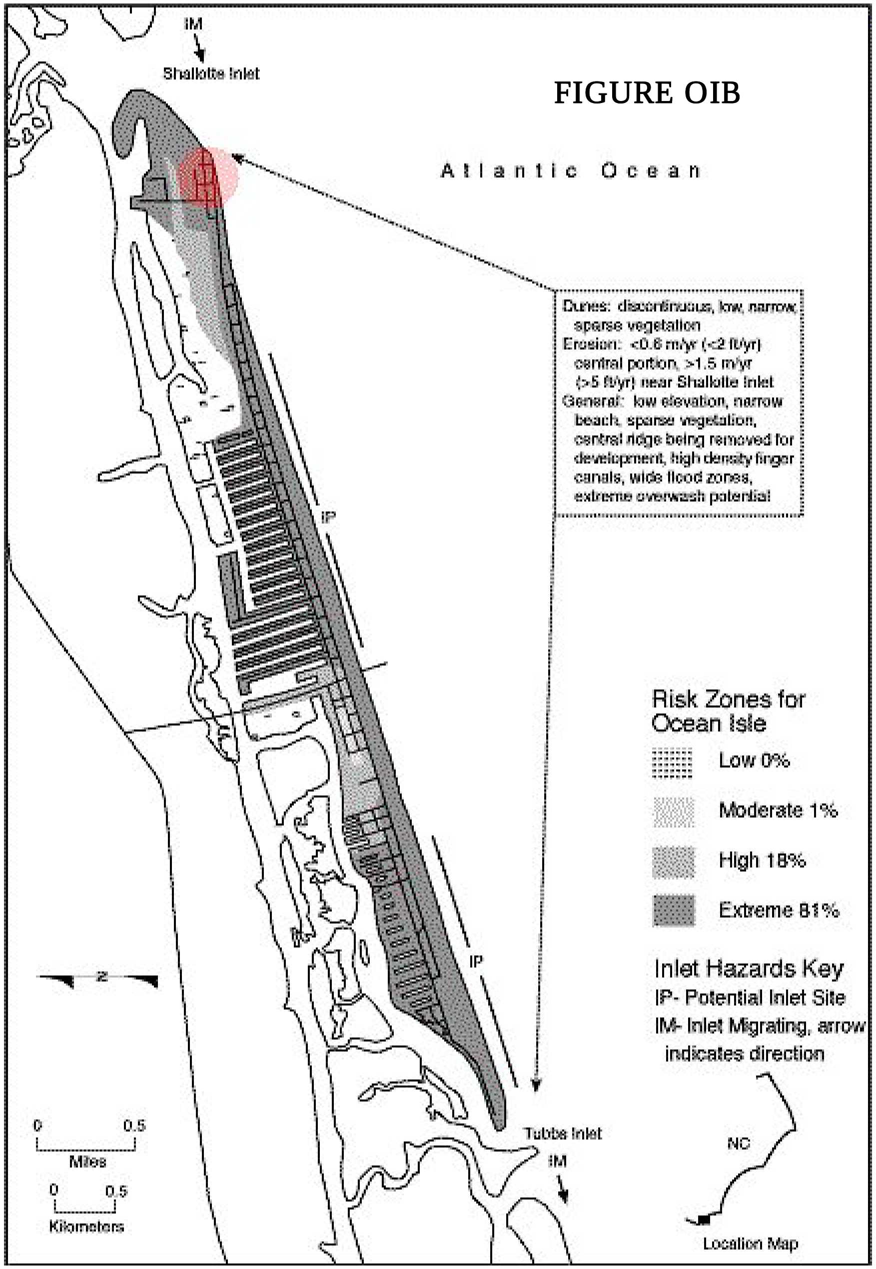
Implementing actions:

- OIB should investigate the feasibility of becoming a FEMA "Project Impact" community.
- OIB should consider the applicability of requiring "V Zone" structural certification for all structures located in the 100-year NFIP flood zone.

Protect the physical and visual integrity of the estuarine shoreline.

Implementing actions:

- Actively pursue all sources of funding including a Capital Improvements Program to provide funds for open space and estuarine access projects.



- Develop ordinances that would exclude development detrimental to the estuarine environment.

Increase the amount of recreational open space along the ocean and estuarine shorelines and increase open space in other areas.

Implementing actions:

- OIB should investigate the feasibility of implementing a facility fee schedule that will require payment of fees from new development that will be used for the acquisition of land for ocean and estuarine access areas.
- OIB should submit grant applications for shoreline access projects when the opportunities arise.
- OIB should develop an Open Space Plan designed to identify key locations for land and easement acquisition.

Consider higher flood regulatory standards for vehicle and equipment storage areas and structures that produce, use or store volatile, flammable, explosive, toxic and or reactive materials.

Implementing actions:

- OIB should develop a program to identify businesses and material storage areas where significant amounts of toxic or hazardous products are stored that could be subject to flooding.
- OIB should develop regulations to require fuel tanks, including LP tanks to be adequately anchored to prevent flotation or submersion in the event of flooding.

REFERENCES

Atlantic Beach, Town of Town of Atlantic Beach, North Carolina FY 96 Land Use Plan; 1996

Atlantic Beach, Town of; http://www.atlanticbeach-nc.com/history.htm; 2001

Ayscue, Jon; Hurricane Damage to Residential Structures: Risk and Mitigation; Natural Hazards Research Working Paper #94; Natural Hazards Research and Applications Information Center; Institute of Behavioral Science; University of Colorado; November, 1996

Burton, 1978

Bush, David and Coburn, Andrew; Site-Specific Coastal Storm Hazard Assessment: Kitty Hawk, Kill Devil Hills and Nags Head, North Carolina; Duke University PSDS, Durham, NC 1992

Bush, David M. and Pilkey, Orrin H., 1994. Mitigation of Hurricane Property Damage on Barrier Islands: A Geological View, In: Finkl, C.W., Jr., (ed.), Coastal Hazards: Perception, Susceptibility and Mitigation. Journal of Coastal Research Special Issue No. 12, p. 311-326.

Bush, David; Pilkey, Orrin; Mitigation of Hurricane Property Damage on Barrier Islands: A Geological View; Journal of Coastal Research; Issue 12, Chapter 22; 1999

Bush, David; Pilkey, Orrin; Neal, William; Living by the Rules of the Sea; Duke University Press; Durham, NC and London, UK; 1996

CAMA; North Carolina Coastal Area Management Act; NC Division of Coastal Management, Raleigh, NC 1974

Carolina Beach, Town of; 1997CAMA Land Use Plan – Town of Carolina Beach, North Carolina; Town of Carolina Beach Planning Board, Glenn Harbeck Associates; Carolina Beach, NC; 1977

Cleary, William and Hosier, Paul; New Hanover County: Then and Now A Guide to the New Hanover County Beaches; NC Sea Grant Publication UNC-SG-77-14, Raleigh, NC; 1977

Cleary, William and Marden, Tara; A Pictoral Atlas of North Carolina Inlets; University of North Carolina, Wilmington; North Carolina Sea Grant Publication UNC-SG-99-04; Raleigh, NC; 1999

Cleary, William; UNCW Center for Marine Science; http://www.uncwil.edu/cmsr/; 2001

Coburn, Andrew; Personal Observation; October, 1999

Federal Emergency Management Agency; National Flood Insurance Study: Topsail Island, North Carolina; Washington, DC; 1996

Long Island Regional Planning Board, Hurricane Damage Mitigation Plan for the South Shore of Nassau and Suffolk Counties, New York. Hauppauge, NY. 196 pages. 1984.

Nags Head, Town of; Town of Nags Head 1990 Land Use Plan Update; Town of Nags Head, NC; Nags Head, NC, 1990

Nags Head, Town of; Town of Nags Head 2000 Land Use Plan; http://www.townofnagshead.net/departments/planning/downloads/lup042001.pdf, Town of Nags Head, NC; Nags Head, NC, 2000

National Weather Service, Historical Hurricane Track Information, http://www.nws.noaa.gov/er/akq/hist.htm, 2001

NOAA; The National Geophysical Data Center; http://www.ngdc.noaa.gov/mgg/coastal/grddas02/grddas02.htm; 2001

North Carolina Division of Coastal Management, Average Long Term Erosion Rate Maps for North Carolina, Raleigh, NC 1992

North Carolina Office of State Budget, Planning and Management; http://osbpm.state.nc.us/index.html 2001

North Topsail Beach, Town of; Town of North Topsail Beach North Carolina 1996 Land Use Plan; Holland Consulting Planners; Wilmington, NC; 1996

NRC (National Research Council), Facing the Challenge, The U.S. National Report to the International Decade of Natural Hazard Reduction World Conference of Natural Disaster Reduction, Washington, DC: National Academy Press, 78 p. May 23*27, 1995

Ocean Isle Beach, Town of, Beach Nourishment Web Site, http://www.oibgov.com/renourishment.htm, 2001

Ocean Isle Beach, Town of, Town of Ocean Isle Beach 1997 CAMA Land Use Plan Update; Hayes and Associates; Wilmington, NC; 1997

Pielke, Jr., R.A., and C.W. Landsea, Normalized hurricane damages in the United States, 1925-1997. *Weather and Forecasting*, **13**, 351-361. 1998

Pilkey, O. H., Jr., Neal, W. J., Pilkey, O. H., Sr., and Riggs, S. R., From Currituck to Calabash, Living with North Carolina's Barrier Islands: Durham, North Carolina: Duke University Press, 245 p. 1978.

Pilkey, Orrin; Bush, David, Neal, William; Storms and the Coast; Unpublished paper; 1996

Pilkey, Orrin; Neal, William; Riggs, Stanley; Webb, Craig; Bush, David; Pilkey, Deborah; Bullocik, Jane; Cowan, Brian; The North Carolina Shore and Its Barrier Islands: Restless Ribbons of Sand, Duke University Press, 1998

Riggs, Stanley; Role Of Geologic Framework, Physical Dynamics, and Sand Resource Potential for Beach Nourishment on the North Carolina Outer Banks; Abstract; GSA Meeting; http://gsa.confex.com/gsa/2001SE/finalprogram/abstract_4513.htm; Session 16; Raleigh, NC April, 2001

Stanczuk, D.T., 1975. Effects of development on barrier island evolution, Bogue Banks, North Carolina. Unpublished Master's Thesis, Duke University, Department of Geology, Durham, North Carolina, 126 p

Texas General Land Office; Dune Protection and Improvement Manual for the Texas Gulf Coast; http://www.glo.state.tx.us/coastal/dunemanual/walkovers.html; 2001

United States Army Corps of Engineers; http://cirp.wes.army.mil/cirp/structdb/structdb.php3?id='181' 2001

United States Census; http://quickfacts.census.gov/qfd/states/37000.html; 2001

University of North Carolina Wilmington; Center for Marine Science; http://www.uncwil.edu/cmsr/, 2001

US Army; Carolina Beach and Vicinity, North Carolina; Washington, DC: May 1962

USGS, Sidescan-Sonar Imagery of the Shoreface and Inner Continental Shelf; U.S. Geological Survey Open-file Report OF 98-616; Wood Hole, MA, 1998

Wrenn, Lee; Ocean Isle Beach Renourishment Project Home Page; http://www.seashell.com/oibhome.htm; 2001