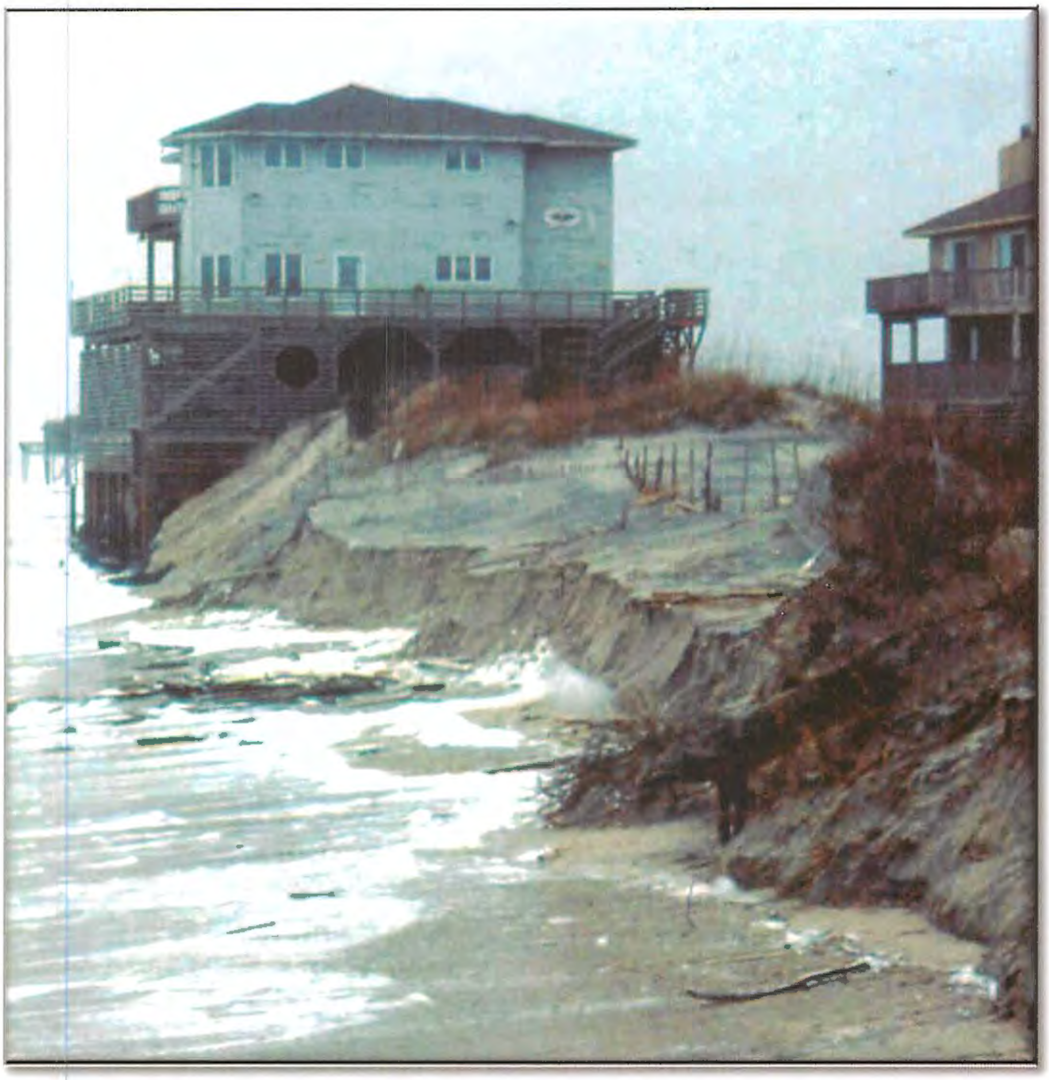
# Coastal Processes and Conflicts: North Carolina's Outer Banks

## A Curriculum for Middle and High School Students



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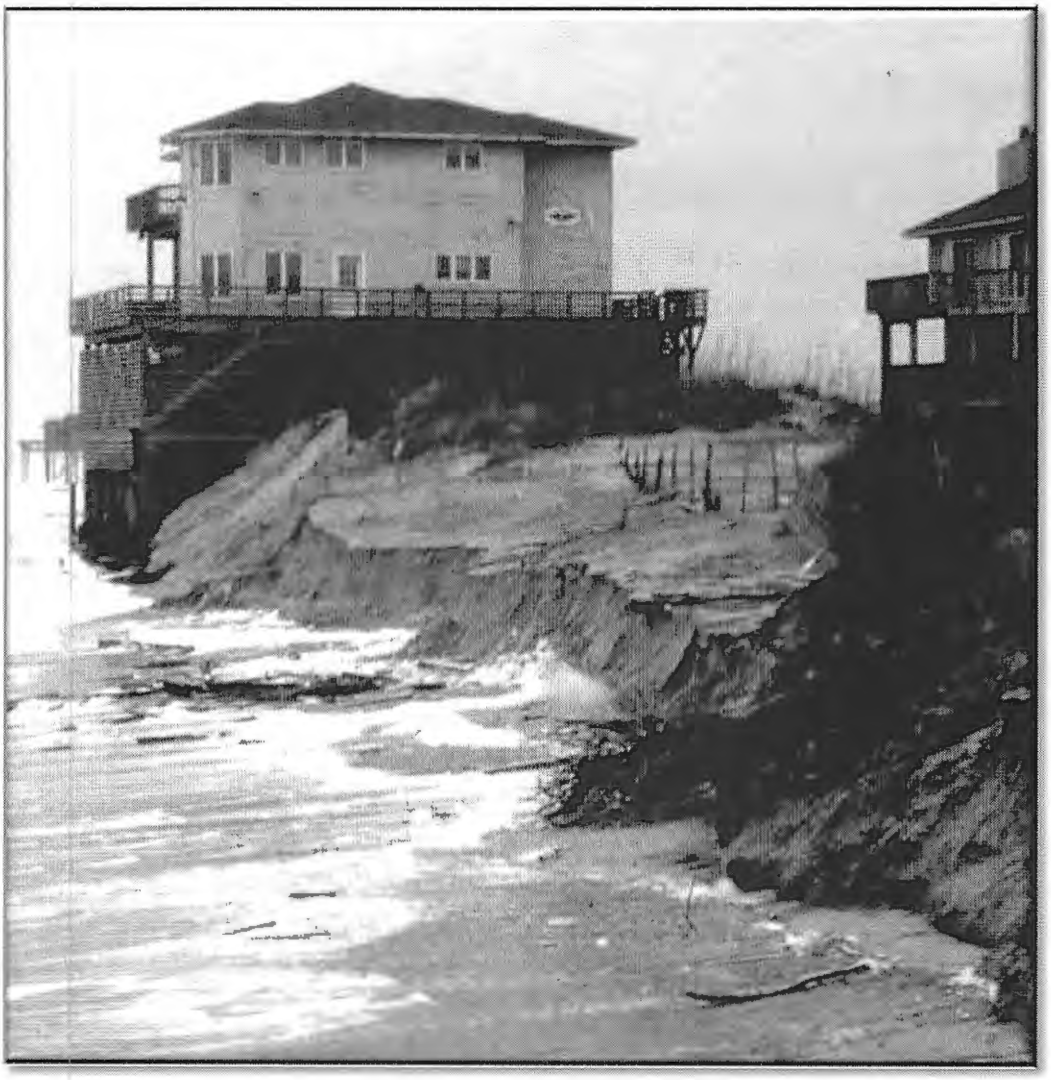

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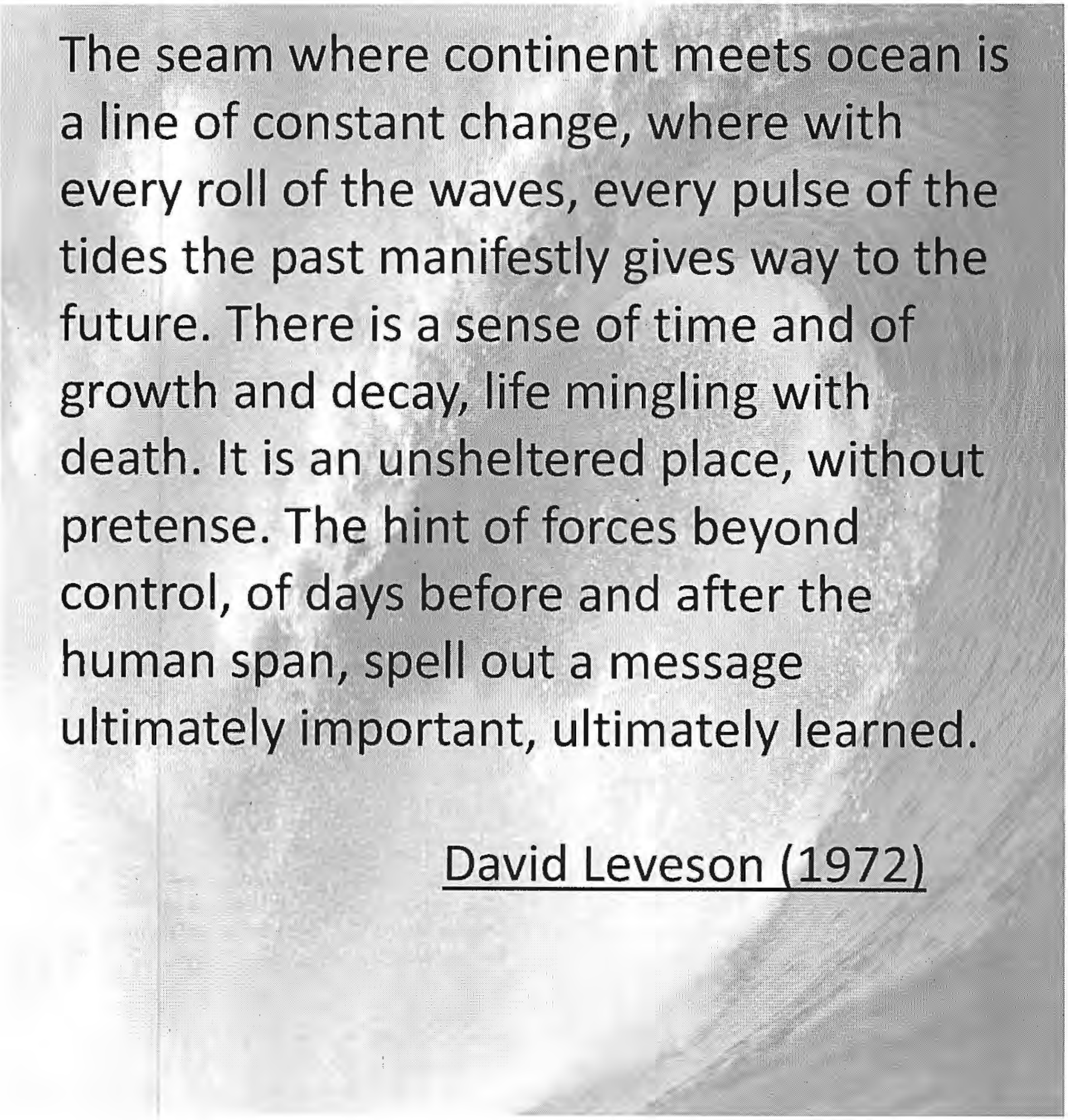

The seam where continent meets ocean is a line of constant change, where with every roll of the waves, every pulse of the tides the past manifestly gives way to the future. There is a sense of time and of growth and decay, life mingling with death. It is an unsheltered place, without pretense. The hint of forces beyond control, of days before and after the human span, spell out a message ultimately important, ultimately learned.

David Leveson (1972)

## THE AUTHORS

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The authors offer special thanks to the hardy band of teachers and students who investigated their sites and contributed their ideas and expertise to this curriculum product.

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# PREFACE

North Carolina's Outer Banks beckon visitors from all over the world to the sandy beaches, expansive sounds, and wealth of natural attractions found along the barrier islands. Ironically, the natural resources that draw so many to the barrier islands are being threatened by human modifications made to support the ever increasing numbers of inhabitants and visitors. Inevitably, the natural coastal processes continue to exert themselves, triggering incessant changes—often in conflict with the activities of humans. The purpose of this curriculum is to facilitate for students an understanding of coastal and human processes and conflicts that exist on the Outer Banks.

As participants in Project Sea-View, a team of students, teachers, scientists, and science educators explored sites along the Outer Banks—recording observations, taking measurements, and interviewing residents, politicians, government managers, and business personnel. Their reports form the underlying structure of the units, all of which connect coastal explorations to investigations that students can conduct in their own classrooms and communities. The curriculum was designed for use by high school or upper middle school students, but ingenious teachers in every grade can customize aspects of the product for their use.

North Carolina Sea Grant funded Project Sea-View to fill the need for curriculum materials in coastal environmental science. By highlighting North Carolina's dynamic Outer Banks as a field laboratory, the Sea-View team addresses erosion and other natural processes that occur throughout the planet. Much of the scientific information and many of the figures are adapted from *Drowning the North Carolina Coast: Sea-Level Rise and Estuarine Dynamics* by Stanley R. Riggs and Dorothea V. Ames, a publication of North Carolina Sea Grant in partnership with the N.C. Division of Coastal Management and the Albemarle-Pamlico National Estuary Program.

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SUGGESTIONS FOR TEACHERS:

This curriculum contains a great deal of information about North Carolina's Outer Banks, including processes that are at work throughout the state and beyond. For that reason, the specific context of the Outer Banks is a setting through which you may facilitate conceptual understandings in your students that relate to many earth processes and environmental concerns that occur in multiple settings. You are encouraged to expand lessons to enhance ideas of your choosing.

The document uses photographs, graphs, and charts to illustrate many of the concepts that are addressed. The student lessons are primarily document-based, relying heavily on the use of visual representations—acknowledging that the combination of spoken words, written words, and visual representations will provide a variety of strategies for diverse learners. The skill of map reading and graph interpretation is of primary importance in science; therefore, the authors intend for teachers to take time to walk their students through these processes until students are adept at interpreting these types of representations. The text is written at an adult reader's level—probably too advanced for many of your students. It is intended to provide extensive background information for you so that you may use your best judgment in designing appropriate lessons for your students—using the activities provided or others of your choosing.

In Part 2, the focus is on a specific site explored by the Sea-View teams. It will provide occasions for students to conduct outdoor explorations and to examine the characteristics of local sites, with superb opportunities for student projects.

The teacher's edition of the curriculum offers a Learning Cycle approach that engages students and involves them actively as a first step, before the teacher provides direct instruction. Although there are many versions of a learning cycle, the one chosen for this curriculum consists of these stages: Engage, Explore, Explain, Extend, Evaluate. This strategy provides a common experience for the students early in the lesson, to which the teacher can later relate concepts that are important. Research on how people learn emphasizes the importance of connecting new information to prior knowledge and/or experiences. With all of the attention given to "inquiry learning" (and justifiably so), there may be a misconception that students should be discovering scientific knowledge on their own all the time. In reality, teachers are the experts in the classroom.

Allowing students to explore on their own with resources is a wise way to begin lessons, but there is a point at which the teacher's knowledge and skills are needed in the process—to bring in the knowledge base provided by scientists and to address misconceptions. In the 5-E learning cycle model, the place for direct instruction is in the "Explain" phase. The key to helping students understand the scientific concepts presented by the teacher is to connect over and over again to the exploration that the students have previously completed. Students then have a concept to which they can link new understandings. Lecturing to students about brand new ideas without making connections to something familiar is a set-up for failure. Because the prior knowledge and experience of the students in a single classroom is always varied, offering a common experience (the "Explore" phase) to which all other ideas are connected insures a level playing field for students.

The stages of the 5-E strategy are explained more fully below:

- <u>Engage:</u> Use any (usually brief) introduction to the lesson that captures students' attention. Examples may include a short reading, a demonstration, a slide or poster, or a brief classroom discussion.

- Explore: During the exploration, students work in groups or alone to accomplish a task of some sort—using resources provided by the teacher. Examples may include a pencil and paper exercise, a lab, an outdoor problem-solving activity, an Internet assignment, or a library assignment.
- Explain: This phase is crucial. It is the "meaning making" step in the process, the place where students explain the results of their exploration, receive feedback from other students and/or the teacher, and participate in scientific discourse. It is a place where the teacher plays a key role in asking questions to stretch students' thinking and to address misconceptions. It is also the place where the teacher takes up where the students left off, bringing additional information to students that relates to their exploration and explanations through direct instruction or other teaching strategies. This is the point where the knowledge base provided by scientists is connected to the concepts students have developed during their exploration.
- Extend: The extension activity may be an additional exploration that reinforces ideas addressed previously or that leads students to new ideas. In some cases the extension may serve as an evaluation (see below).
- Evaluate: The extension exercise may actually serve as an informal evaluation of student understanding. For example, if the exploration involved map reading, the extension might be an additional map reading problem that assesses students' skills. The evaluation may be a more formal quiz or test. It is important, however, to evaluate at least informally at frequent intervals to be sure students understand key concepts. To wait until a test that has implications for student grades is too late. By the time you give a test, you should be fairly well convinced that your students have understood the important concepts you have targeted.

You, as the teacher, are resourceful enough to use this product in a way that is productive for you and your students. The 5-E format is just one idea that might help you sequence your instructional strategies in a way that supports student understanding and not just memorization.

The rich content in each chapter is the "fodder" from which you choose the concepts and ideas most important for your students. There is a great deal of information for the teacher. Your instructional goals and your knowledge of your students will determine how much of the content you choose to present to students. Whatever you decide, the authors are hopeful that you yourself will gain a greater knowledge of North Carolina's coastal resources and a deeper understanding of the natural processes that occur along the Outer Banks.

**Note**: The first lessons in *Part 1* focus on geologic time and the processes that formed the three geologic provinces of North Carolina, including tectonic processes. Teachers should have addressed tectonic processes in detail before beginning these lessons. The lessons will provide a relevant application of what students have already learned about plate tectonics, the formation and break-up of Pangaea, and other global changes.

***Student handouts are printed at the back of this document. An accompanying CD provides color slides of the figures used in student lessons.**

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# PART 1: THE COASTAL SYSTEM OF NORTHEASTERN NORTH CAROLINA

Figure 1-1. A satellite image of the Northern Coastal province of North Carolina extends from Cape Lookout north to the mouth of the Chesapeake Bay in Virginia. The image shows the fresh-water riverine systems, vast network of brackish-water estuaries, and the salt-water oceanic system that is separated by the barrier island sand dam. A few small inlet/outlets allow interchange with the Atlantic Ocean. Notice how the rivers widen to become drowned-river estuaries as they approach and interact with sea level. Image is courtesy of Earth Sciences and Image Analysis Laboratory, NASA Johnson Space Center. Image STS 095-709-14 (*http://eol.jsc.nasa.gov*)

## Lesson One: Geologic Development of Coastal North Carolina

### Background Information for Teachers:

Figure 1-2 is a 1999 satellite image of northeastern North Carolina showing the five sites explored by the Sea-View teams: Avon-Buxton, Oregon Inlet, South Nags Head, Jockey's Ridge, and Nags Head Woods—Nags Head Cove. Hurricane Floyd made landfall on Sept. 15-16, 1999. The satellite image was taken on Sept. 23, 1999, when the rivers were flowing at peak flood stage. You can see the dark-colored water carried by the rivers into the estuaries.

Figure 1-1 shows the fresh-water river systems of northeastern North Carolina, a vast network of drowned-river estuaries where the riverine-fresh water and ocean-salt water mix to form the brackish-water estuarine system. The barrier islands act as a sand dam with a few inlet/outlet systems that allow water to flow between the Atlantic Ocean and the sounds. Although there are many interesting sites along North Carolina's coastal system, the Outer Banks team focused on a few sites in a relatively small area as representative examples of critical processes and conflicts.

The history of development in coastal North Carolina is unlike many other human endeavors because of the high-energy and dynamic character of the coastal system. The formation of the modern North Carolina coastal system has taken place during the past 10,000 years and continues today as a work in progress. More importantly, change is the only constant within the coastal system and happens at much faster rates than changes occurring on more stable inland terrains.

Native Americans inhabited North Carolina prior to 10,000 years ago. However, little record of their occupancy of the coastal zone exists today. Even the record of the first European settlement on the north end of Roanoke Island in 1584 to 1585 has been obliterated by the dynamic processes that eroded away large portions of the island. The processes of change continue to take their toll today as every nor'easter and hurricane place their mark upon the shifting sands of time. If the rapid rates of coastal evolution presently taking place continue, no great remnants from our present coastal civilization will survive into the future. This is our coastal heritage.

Figure 1-2. **This satellite image shows the Sea-View site locations. The image is a joint product of the NASA Landsat Project Occupancy Office, Goddard Space Flight Center, and the U.S. Geological Survey EROS Data Center. Figure is modified from Figure 2-1-3, p. 19 in Riggs and Ames (2003).**

Geologists are generally perceived as dealing with millions of years of geologic time. It is true that, when considering earth history, geologists do think in terms of millions, and even billions of years. Table 1 presents a brief and general summary of critical periods in the formation of North Carolina's Appalachian Mountains and the Atlantic Ocean. From these two major tectonic events in Earth history came the development of the Atlantic continental margin with its coastal plain and continental shelf. The modern coastal zone is a product of and has inherited its characteristics from this Earth history, in the same way that you are a product of and have inherited your characteristics from your family history.

A good example of the long-range geologic time frame is the formation of the super-continent Pangaea during the Paleozoic in which all of the earth's land masses collided. As a result of these collisions, Pangaea and the Appalachian Mountains (Figure 1-3) formed in a three-part sequence during the Paleozoic era (Table 1). Subsequently, the super-continent Pangaea began to break up during the Mesozoic era. Europe and Africa began to break off of North and South America beginning about 225 million years ago (mya) and formed the new Atlantic Ocean in the gap between the continents starting about 180 mya. As plate tectonics systematically moved the continents further apart through time, the Atlantic Ocean grew wider and wider. Along with the opening of the Atlantic Ocean came the deposition of marine sediments on the continental margin to form the North Carolina coastal plain, continental shelf and continental slope, and our modern coastal system (Figure 1-3). This Coastal province of low and flat landforms was produced largely from the sediments that were being weathered and eroded off the older and higher Appalachian and Piedmont provinces and carried to the ocean by an extensive drainage system, as is still happening today.

**TABLE 1. SUMMARY OF THE TECTONIC FORMATION OF THE APPALACHIAN PROVINCE, PIEDMONT PROVINCE, ATLANTIC OCEAN, AND ATLANTIC CONTINENTAL MARGIN THAT CONTAINS THE COASTAL PLAIN AND CONTINENTAL SHELF PROVINCES.**

I. THREE EPISODES OF COLLIDING TECTONIC PLATES

Orogenies or Mountain Building Episodes resulting from convergent plate boundary dynamics—compressional forces pushing together

A. Taconic Orogeny (Ordovician Period ~480 to ~440 mya*)
B. Acadian Orogeny (Devonian Period ~380 to ~340 mya*)
C. Alleghanian Orogeny (Carboniferous to mid-Permian ~300 to ~240 mya*)

II. CONSEQUENCES

A. Collision and incorporation of volcanic islands and continental fragments with Proto-North America
B. Closure of Proto-Atlantic Ocean
C. Formation of Appalachian and Piedmont Provinces
D. Intrusions of Spruce Pine pegmatites in the Appalachian Province and granite plutons in the Piedmont Province (major sources of economic mineral deposits today)
E. Formation of PANGAEA super continent that existed from mid-Permian to lower Triassic (~300 to ~240 mya*)

III. RIFTING OF PANGAEA SUPER CONTINENT

A. Breakup of Pangaea resulting from divergent plate boundary dynamics—tensional forces pulling continental fragments apart
B. Breakup forms Rift Valleys (upper Triassic to lower Jurassic ~225 to ~180 mya*)
C. Triassic rift valley deposition by volcanic, alluvial, riverine, and lakes sedimentation
D. Appalachian and Piedmont Provinces supply weathered sediments to developing river drainage system that will deliver sediments to the rift valleys, continental margin, and new Atlantic Ocean

IV. CONSEQUENCES

A. Drowning of rift valley and formation of the Atlantic Ocean (Jurassic Period ~180 to ~150 mya*)
B. Formation of Coastal Plain and Continental Shelf Provinces (Cretaceous to Quaternary Periods ~150 mya* to TODAY)
C. Repeated events of continental margin submergence by the Atlantic Ocean deposited sediment wedge that ranges from 0 feet thick at the outer Piedmont edge to 10,000 feet thick at Cape Hatteras and ~40,000 feet thick at the outer edge of the continental margin
D. Deposition of clastic sediments derived from weathering and erosion of the Appalachian and Piedmont Provinces were mixed with marine chemical sediments
E. Today's surface morphology of the Coastal Plain has been developed by multiple marine high stands that flooded the Coastal Plain and was then severely modified during subsequent low stands by the incisement of the drainage system into the marine sediments

* mya = millions of years ago

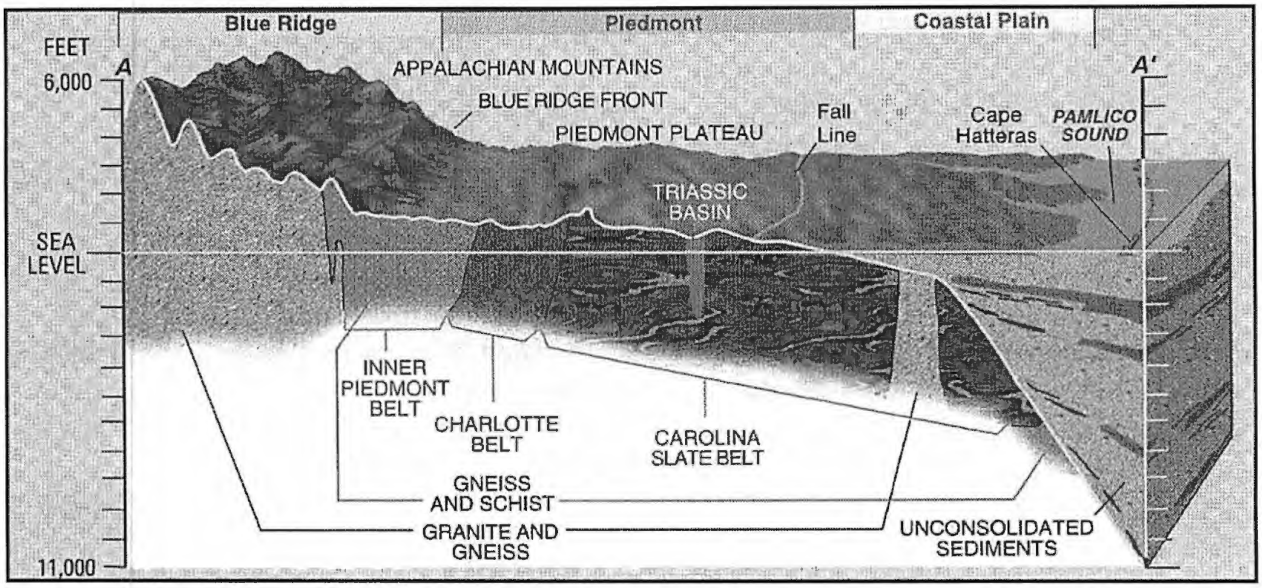


**Figure 1-3**. This diagram shows the three geologic provinces of North Carolina. See Table 1 for a brief evolutionary history of the provinces. The young Coastal province was produced largely from sediments that were being weathered and eroded off the older and higher Appalachian and Piedmont provinces. The sediments were carried to the ocean by the river drainage system and deposited in the shallow coastal and marine environments of the more recently formed Atlantic Ocean (*http://www.geology.enr.state.nc.us*).

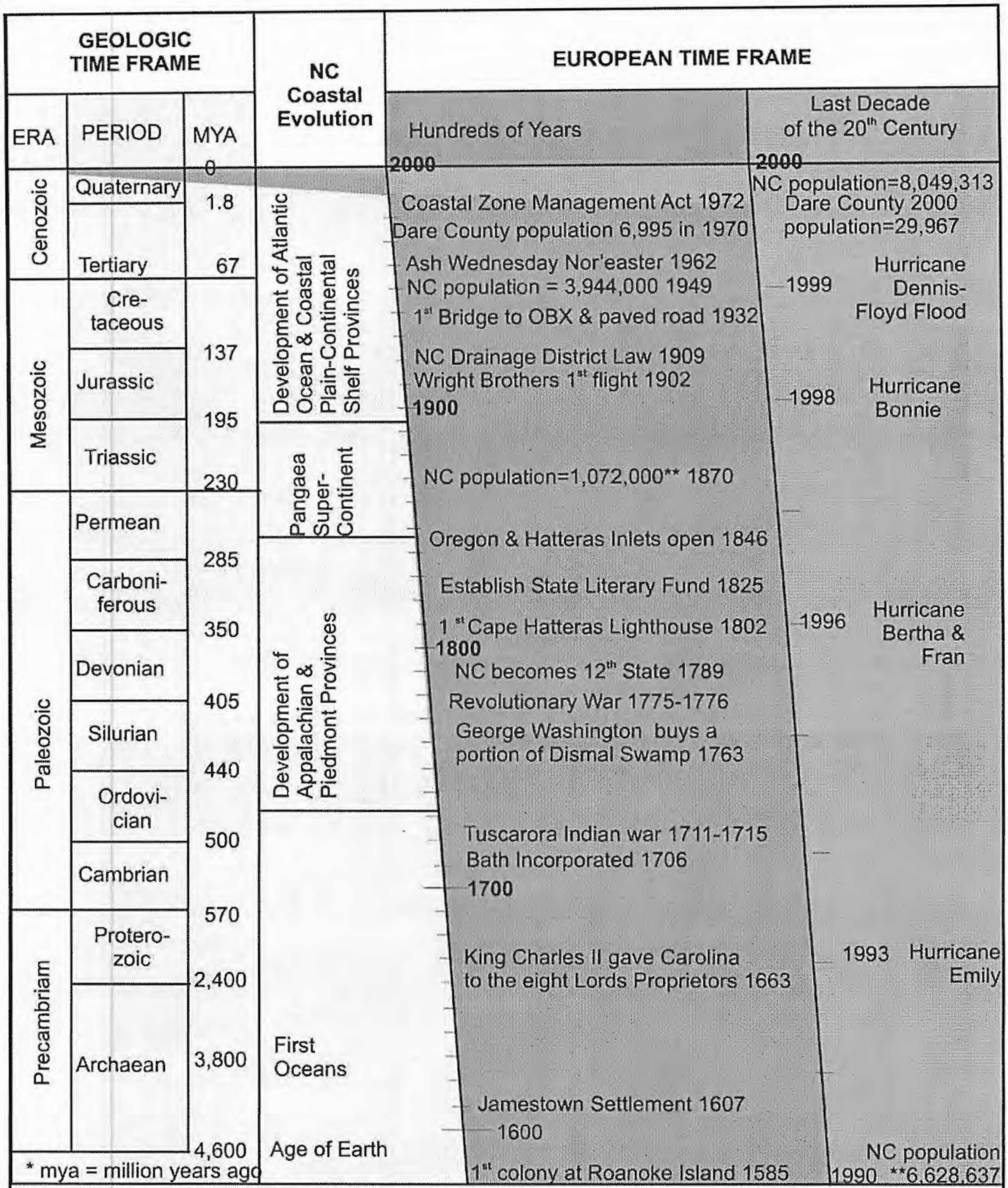
## Lesson Two: Time

### Teacher Background Information:

The evolution of North Carolina has taken place over many hundreds of millions of years as indicated in Table 1. However, geologists do not deal only with billions and millions of years. When considering modern earth processes such as earthquakes, volcanic eruptions, hurricanes and river floods, the time scales shift to hours, days, years, decades, and centuries. Likewise, in considering high-energy coastal systems, geologic time may be experienced during a trip to the beach, a winter storm, an individual life span, or a few generations. Thus, modern coastal processes result in geologic events that range in human time frames from individual storm events to the rise and fall of specific civilizations. At this scale, *geologic time is human time*!

Figure 1-4 contrasts the long range geologic time that reaches back to the early days of the earth's formation 4.6 billion years ago with more recent human time frames, including the last 400 years and the last 10 years. On the shorter human time frame in Figure 1-4, the last 400 years would be represented by a microscopic dot at the end of the long-term time line. Study the figure so that you understand what it represents.

A good example of geologic change in a short time span is the opening of the inlet on Hatteras Island formed during Hurricane Isabel on Sept. 18, 2003 (Figure 1-5). Panel A is a 1998 aerial photograph of Hatteras Island, east of Hatteras Village. Panel B was taken seven days after Hurricane Isabel. The three red dots are located at the same place in Panels A and B. Panel C is a ground photo of the new Isabel Inlet with what's left of N.C. Hwy. 12. The photos represent a modern coastal process that results in geologic change occurring in the *human time frame* of a few hours.



http://www.census.gov/prod/2001pubs/statab/sec01.pdf

**Figure 1-4.** This geologic time chart contrasts long-range geologic time that reaches 4.6 billion years back to the earth's formation with the more recent human time frame since European colonization of North Carolina (the last 400 years) and the last decade of the 20th century.

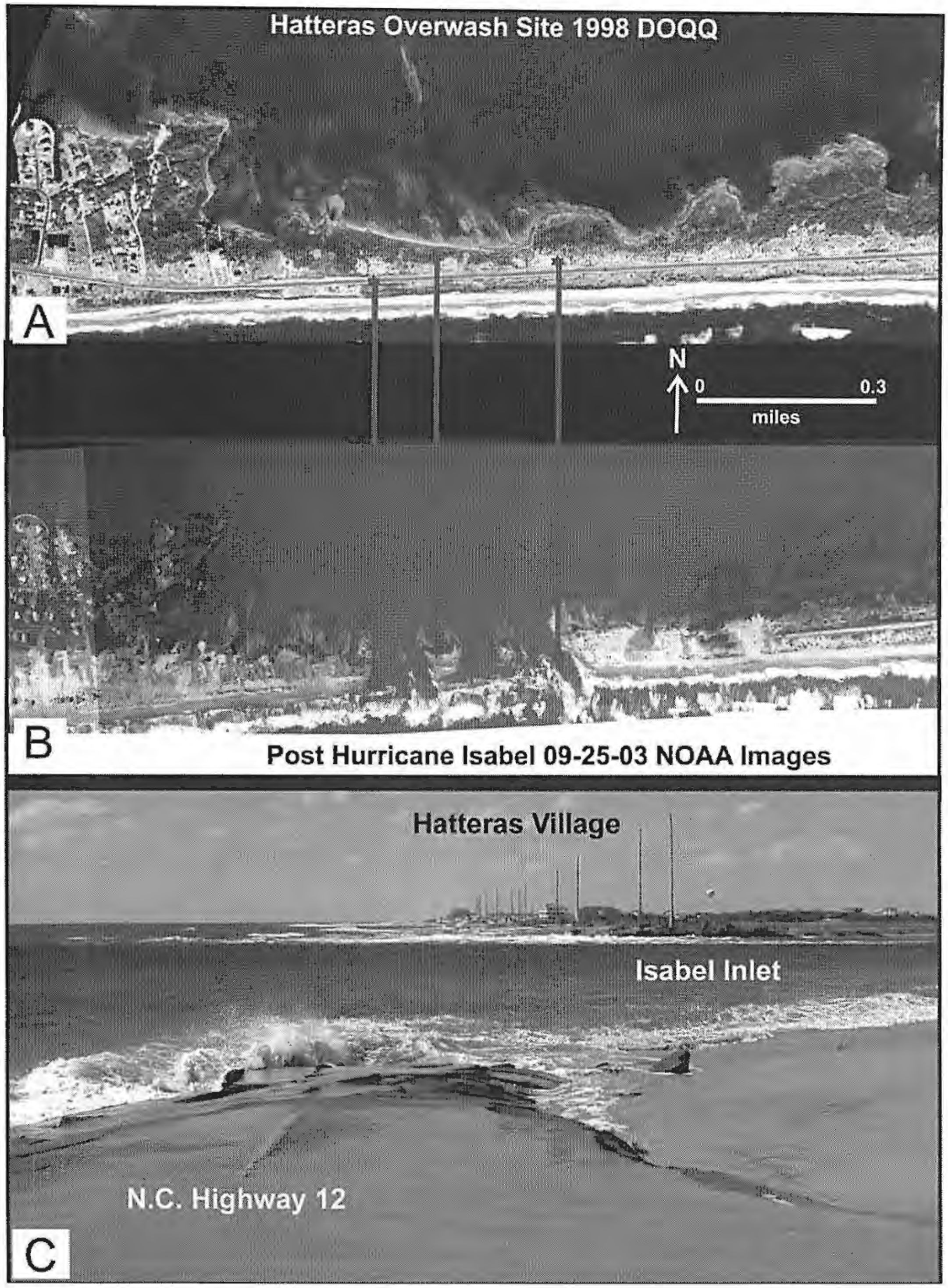


Figure 1-5. Aerial and ground photographs show the site of Isabel Inlet that opened on Sept. 18, 2003 in response to Hurricane Isabel. Panel A. A 1998 false color aerial photograph shows the east end of Hatteras Village and the potential inlet site. Panel B. An aerial photograph of the same area taken on Sept. 25, 2003 shows the location and three-part character of Isabel Inlet. The red points and associated lines on Panels A and B represent exact common points. Panel C. A ground level photo looks west across Isabel Inlet toward Hatteras Village with the "going-to-sea" N.C. Hwy. 12 in the foreground. Figure 8-4-18, p. 141 in Riggs and Ames (2003).

## Student Learning Cycle

**Engage:**

a. Show students a slide of Figure 1-2. As a part of class discussion, have students identify all the rivers, sounds, and inlets in the satellite image. If your school is located within this area of North Carolina, have students determine its estimated location on the slide. Note the sites that the Sea-View teams explored. Mention that the Avon-Buxton site will be explored in more detail in later lessons. Have any of your students been to any of these sites? How would they describe them? Explain that these features of eastern North Carolina were the result of changes that occurred on the planet through millions of years, resulting from dramatic mountain-building episodes, separation of giant land masses, and the gradual build-up of the coastal plain from materials originating from both the Appalachian and Piedmont provinces and from sediments in the ocean. Students will now explore those processes.

b. Show students a slide of Figure 1-5 (opening of inlet by Hurricane Isabel in 2003). Ask students how long they think it took for the hurricane to wash through the island and form this inlet. (This event happened during a period of 24 hours or less.) Some earth-changing processes take much, much longer—periods of time that are so great they are almost incomprehensible to us humans who live such a short time on the planet, relative to the age of the planet.

c. Show students a slide of Figure 1-4. Explain that this chart compares geologic time to human time, but that they will analyze the details of the chart as a part of their assignment.

**Explore:**

Materials Needed:
Slide of Figure 1-5
Slide of Figure 1-4
Copies of Figure 1-5 (one per group)
Copies of Figure 1-4 (one per student)
Rulers

Divide class into groups with two assignments:

Part 1: Provide each group a handout of Figure 1-5. Leave the color slide visible because the black and white handout is not as distinct. Students may refer to both in working on their assignments.

Have students complete this assignment: Calculate (in feet) the width of the new Isabel Inlet formed by Hurricane Isabel's storm surge. (This is an exercise in scale, which is a skill useful in every science discipline.)

Part 2: Provide each student with a handout of Figure 1-4. Keep the slide of Figure 1-4 projected for reference. Have groups answer these questions related to Figure 1-4:

1. Look at the two main headings related to time frames—geologic time frame and European time frame. Which one is divided into millions of years? Which one is divided into hundreds of years or smaller divisions of time?
2. In the geologic time frame, what does mya stand for?
3. Which geologic era is the most recent? The farthest away in time?
4. From this chart, how old is the earth? (Hint: to turn each number into millions, add six zeroes.)

5. Approximately how many years ago did the development of the Appalachian and Piedmont provinces of North Carolina begin?
6. About how many years ago did the Super-Continent, Pangaea, begin to form?
7. About how many years ago did the Atlantic Ocean begin to form?
8. Which one(s) of the processes in #5-7 involved the collision of tectonic plates?
9. Which one(s) of the processes involved the pulling apart of tectonic plates?
10. You were present for at least part of the last decade of the 20th century. In the margin of Figure 1-4, write in at least five human events (historical or personal) that occurred in that time frame. Write them in correct sequence.

**Explain:**

When students have completed their group assignments, engage them in a discussion of their results. Ask questions that allow them to explain their thinking. This is the time for you to start with their experience and to present information of your choosing from the teacher background information or other sources. Possible topics you might address include: human time versus geologic time, North Carolina geological history (the big picture), formation of Spruce Pine pegmatites and granite plutons (and other N.C. minerals), erosion versus deposition as related to formation of the coastal plain, etc.

**Extend:**

Use Figure 1-3 as the basis for a homework assignment, classroom discussion, or student projects. These questions might be used:

1. Using your textbook, library resources, or reliable Internet sites, research and explain the following terms:
    a. granite
    b. pluton
    c. pegmatite
2. Find Spruce Pine on a map of North Carolina. What is mined in the Spruce Pine area? How are the products from these mines used in our society?
3. Find Rocky Mount on a map of North Carolina. What is mined in the Rocky Mount area? How are the products from these mines used in our society?
4. Study Figure 1-3. What is the fall line? What is the difference between the topography, soil types, underlying rocks, age and processes of formation to the east and west of the Fall Line?
5. How do the Coastal Plain and Piedmont provinces differ from the Appalachian province?
6. Explain why there are such differences between the three major provinces of North Carolina and explain how this affects the way people make a living in the different regions.

**Evaluate:**

List in chronological order the major geological events involved in the development of the North Carolina's three geologic provinces.

## Lesson Three: Sea-Level Change and Coastal Dynamics

### Teacher Background Information

The long-term processes of climate and sea-level change produce the disequilibrium that results in the reshaping of the North Carolina coastal system by individual hurricanes and northeast storms. Rising sea level slowly and systematically floods up the stream valleys and adjacent land slopes. However, it is wave energy during storms that physically erodes the shoreline and moves it further landward in response to rising sea level. A falling sea level results in the abandonment of an old shoreline, as the contact between water and land slowly migrates seaward.

The Quaternary period of geologic time, the last 1.8 million years of Earth history, was characterized by multiple episodes of glaciation and deglaciation resulting from extreme fluctuations in global climate. The Quaternary is further subdivided into the Pleistocene epoch, better known as the ice ages, and the Holocene epoch, the last 10,000 years of Earth history. The Holocene is the time of warm global climates associated with the ongoing interglacial time period (between major glacial episodes) and has been witness to the development of modern civilization.

From about 10,000 to 20,000 years ago, the Earth was locked in the last of a long series of glacial episodes that occurred during the Quaternary period. During the last ice age, massive glacial ice sheets, often up to two miles thick, covered the northern half of North America, Greenland, northern Europe, northwestern Asia, mountainous portions of South America, and Antarctica. In North America, the ice sheets extended southward to Cape Cod, Long Island, and the Ohio and Missouri Rivers, forcing the climate zones to systematically shift southward.

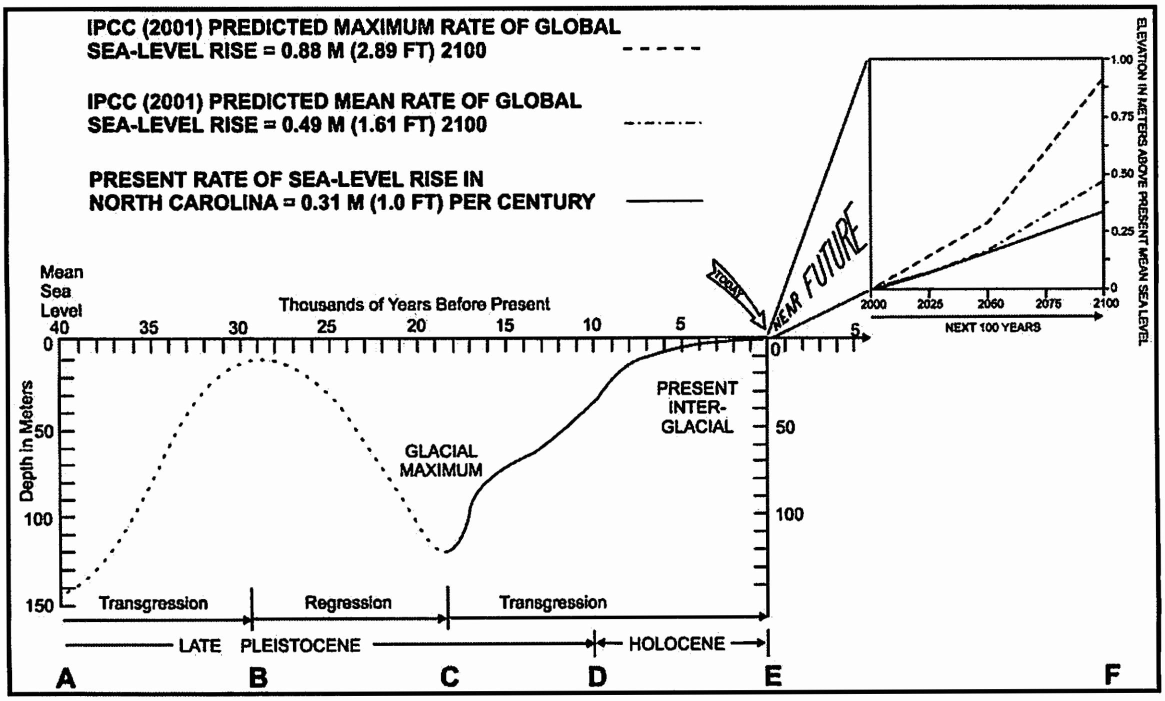
During this time, North Carolina's vegetation included boreal (northern) forest species such as spruce, fir, and jack pine. The climate was cold, semi-arid, and dominated by severe storm activity. The river systems consisted of broad and shallow, sediment choked drainage systems much like you would see in the western United States today. Aeolian (wind-blown) dune fields were common in the river valleys. Because the water that produced these land-based ice sheets was derived from the world's oceans, global sea level was lowered by more than 400 feet worldwide. This drop in sea level placed the North Carolina ocean shoreline on the continental slope between 15 and 60 miles seaward of the present barrier islands, extending the Coastal Plain completely across the present continental shelf (see the continental shelf-continental slope break in Figure 1-17).

Periods of global warming, such as the one that began at the end of the Pleistocene, resulted in deglaciation. Ice sheets began to retreat and discharge the resulting melt-waters back into the world's oceans. The warm climate period that followed is called the Holocene epoch and represents the last 10,000 years of Earth history. During the Holocene interglacial, worldwide sea levels slowly rose to their current level (see the last few decades of sea-level rise in Figures 1-6 and 1-7).

A classic sea-level change curve for the late Pleistocene glacial episode and the subsequent Holocene interglacial is presented in Figure 1-6. The curve for the Holocene post-glacial period suggests a rise in sea level that started at extremely high rates (about 6.6 ft/100 yrs) for a millennium, then slowed to moderate rates (about 3.3 ft/100 yrs) until about 8,000 years ago. At this time the rate of sea-level rise slowed dramatically to the present rates that range from 0.5 to 1.6 ft/100 yrs. However, it has been demonstrated by many researchers, including the authors, that there were numerous brief periods during this history when sea level actually stopped rising and even temporally dropped.

Rising sea level caused the shoreline and coastal system to migrate upward and westward across the continental shelf to its present location during the Holocene. Thus, the North Carolina coast retreated landward between 15 to 60 miles with shoreline recession rates that ranged from an average of 5 ft/yr at Cape Hatteras to an average of 19 ft/yr at Topsail Island. Shoreline recession rates for North Carolina through most of the post-glacial history are generally greater than current average global rates of coastal retreat, which range between 3 to 10 ft/yr.

But there is still a tremendous volume of ice that occurs in the Greenland and Antarctic glacial ice caps. If all of the present glacial ice in these two ice caps were to melt, sea level would be approximately 200 feet higher than at present and much of the modern North Carolina Coastal Plain would be flooded by the ocean. The ocean shoreline would occur approximately along Interstate 95 between Roanoke Rapids and Fayetteville, with the drowned-river estuaries extending up the river valleys to Raleigh and adjacent Piedmont regions. Such advances and retreats of the glacial ice and the global oceans have occurred numerous times during the Pleistocene epoch. Old beach shorelines, such as the Suffolk Scarp and Currituck Peninsula beach ridges (Figure 1-2), clearly demonstrate the location of these ancient shorelines. In fact, the surface sediments, soils, and topography of the Coastal Plain are direct products of these major fluctuations in the Quaternary coastal system.



**<u>Figure 1-6</u>. Generalized sea-level curve for the past 40,000 years and predictions to year 2100 AD. Predictions are based upon IPCC (2001). Figure 6-2-1, p. 62 in Riggs and Ames (2003).**

Data from long-term tide gauge records demonstrate similar rates of sea-level rise for both Charleston, S.C. and Norfolk, Va. (Figure 1-7). Because North Carolina's coastline lies between South Carolina and Virginia, we can infer similar changes, resulting in the ongoing flooding of the low coastal land as well as recession of North Carolina's coastal shorelines.

The Intergovernmental Panel on Climate Change Report in 2001 (Figure 1-6) predicts increased rates of global sea-level rise over the next century in direct response to known rates of global climate warming. Increased rates of sea-level rise will adversely impact coastlines of North Carolina in the following ways:

1. Accelerated rates of coastal erosion and land loss;
2. Increased economic losses due to flooding and storm damage;
3. Increased loss of urban infrastructure;
4. Collapse of some barrier island segments; and
5. Increased loss of estuarine wetlands and other coastal habitats.

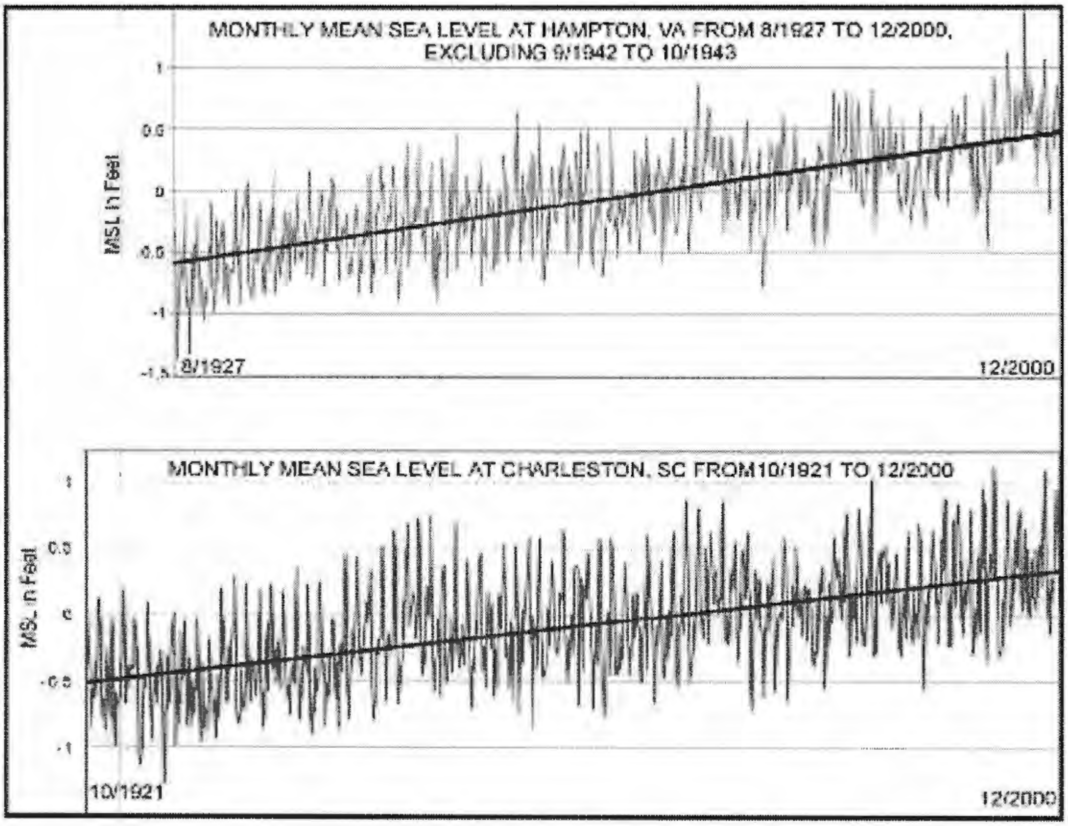


**Figure 1-7. Tide gauge data from Hampton, Va. and Charleston, S.C. demonstrate the rate of ongoing sea-level rise. The plotted data are monthly averages of mean sea level that extend from August 1927 and October 1921, respectively, to December 2000. The heavy line through each plot is the graphical representation of the data trend in a series. It is obtained by regression analysis and shows the net rise in sea level during this time period. Similar tide-gauge data developed at Duck, N.C. by the U.S. Army Corps of Engineers only goes back to 1980, but in a 20-year time period, the data suggest a slightly higher rate of sea-level rise of about 1.5 ft/100 yrs for the Albemarle Sound coastal region. The two sets of tide-gauge data in Figure 1-7 are from the National Oceanographic and Atmospheric Administration (NOAA) National Water Level Observation Network (*www.co-ops.nos.noaa.gov/*). Figure 6-3-2, p. 65 in Riggs and Ames (2003).**

The scientific community has only a moderate understanding of the linkages and controls between global warming and changing magnitude and rate of sea-level response, resulting in limited levels of predictability from a societal point of view. Sea level is rising in North Carolina today at a rate between 1.0 to 1.61 ft/100 yrs. Is this rate of flooding significant for the North Carolina coastal system? On your next trip through the coastal system of the Northern Coastal Province, notice how low and flat the land is—with extensive, water-filled drainage ditches occurring adjacent to the highways. The water in these ditches is generally at or close to sea level, and the roads are built on fill dirt dug from these ditches.

The ongoing rise in sea level results in the continuing upward and landward migration of the shoreline. The specific process of shoreline migration is better known as *shoreline erosion*. Rising sea level across the world means that erosion is common to all of North Carolina's thousands of miles of estuarine and ocean shoreline. The only differences are the rates of erosion that are dependent upon local tectonic changes in the land, the underlying geologic framework, specific shoreline variables, and varying storm conditions. Locally, a segment of the shoreline may appear stable or actually accrete (add on) sediments. Such a situation represents either an anomalous set of local conditions or is ephemeral in nature.

## Student Learning Cycle

### Engage:

Use the following questions to guide a classroom discussion:

1. What evidence supports the idea that sea level changes through time?
2. What effect does climate change have upon sea-level rise or fall? Explain.
3. If sea level is rising in North Carolina, how would that affect the state? How would it affect other states in the U.S.? Other countries?
4. If sea level were to fall, what would be the consequences for North Carolinians?

### Explore:

Materials Needed:

- Copies of Figures 1-6 and 1-7 for each student
- Handout with questions related to Figures 1-6 and 1-7

**Note:** Figure 1-6 is quite complex. Student groups may need teacher guidance to interpret the details of the chart. It is, however, an opportunity to help students learn how to interpret data that is represented in many different formats.

Have students work in groups to answer the following questions related to Figure 1-6.

1. Use Figure 1-6 to answer the following questions.
    a. What does the vertical axis (y axis) represent?
    b. What units are used on the vertical axis?
    c. What is the significance of the graph going from 0 to 150 in the negative direction?
    d. What does the horizontal axis (x axis) represent?
    e. What units are used on the horizontal axis?
    f. What does 10 on the x axis represent?
    g. How is the x axis in the insert different from that of the main graph?

   h. Note the arrow that says "Today." If you were standing on the estuarine shoreline at Morehead City today, what is the mean sea level at that point? Where was the beach 40,000 years ago?
   i. What is happening to the glaciers and sea level between B and C?
   j. What is happening to glaciers and sea level between C and D?
   k. What is happening to sea level between D and E? E and F?
2. From your answers to questions 1a-k, make a statement concerning the relationship between glacier changes and sea-level changes.
3. What does the slope of a line represent on a graph? How would you describe the rate of change in sea level between B and C? C and D? D and E?
4. What do the three lines in the insert (E-F) represent?
5. What inference might you make in the relationship of predicted sea-level change to climate change and the resulting differences in glacial melting rates for the next 100 years?
6. Where was sea level at the beginning of the Holocene when modern human civilization began?
7. If you were standing at the location of today's estuarine shoreline in Morehead City in the year 2100, how much water would you be standing in if sea-level rise continues at its present rate? If sea-level rises at the predicted maximum rate?

**Explain:**
Have groups explain their answers to each question. Encourage discussion of differences among groups, giving time to resolve them. Show a slide of Figure 1-7. Give students time to study the slide and provide their ideas about the implications. As a class, develop answers to these questions regarding Figure 1-7:

Using Figure 1-7, calculate the number of years between 1927-2000 and 1921-2000 and then calculate the average annual rise of sea level for each area. Assuming a constant annual rate of rise for both areas, calculate the total sea-level rise that will have occurred in Hampton by 2027 and Charleston by 2021.

Present any other information you wish to address from the teacher's background information or other sources.

**Extend:**
If all of the present glacial ice in these two ice caps were to melt, sea level would be approximately 200 feet higher than at present and much of the modern North Carolina Coastal Plain would be flooded by the ocean. What would happen to your school if this happened (find the elevation)?

Out-of-class assignment: Find archived newspaper articles that report on any site on North Carolina's coast where rising sea level has affected humans. Summarize the article including, if possible, the extent of sea-level rise, the effects, and the responses of citizens and/or governmental agencies.

**Evaluate:**
Class discussion: What is the evidence that sea level is rising along the North Carolina coast? What has happened to sea level over the last 40,000 years? What is a logical prediction about sea-level rise in the future?

## Lesson Four: Transfer of Energy and the Hydrologic Cycle

### Teacher Background Information:

The shore zone or beach along barrier islands—where water meets the land—is a zone of extremely high physical energy. This energy occurs in the form of waves, currents, astronomical tides and storm tides and is derived from two important sources.

The first and most extensive influence on the coastal system is solar energy, which differentially heats the earth's atmosphere, ocean, and land surfaces. Differential heating drives the great heat pump operating between the air-sea-land interfaces and produces storms and winds that result in wind tides, waves and currents.

The second influence is the force of gravity. Gravity causes rivers to flow downhill and delivers both water and sediments to the coastal system. Also, the gravitational forces acting between the moon, sun, and earth—as they move on their endless journeys through space—produce the astronomical tides and associated tidal currents that are important within coastal systems. These great and continuous inputs of energy into the earth system must either directly do work, be converted to some other form of energy that can do work, or be released back into space. Energy does not just disappear (*Law of Conservation of Matter and Energy*).

The water cycle (Figure 1-8) is a product of this energy and depends on both the energy of the sun and the force of gravity. Solar energy heats the water's surface and then converts liquid water into water vapor that enters the atmosphere. As the vapor cools, heat is released into the atmosphere and the vapor forms droplets that gravity then pulls back to the earth as rain; it can then repeat the process. The process of heat absorption by water in one area and heat release by vapor miles away regulates the temperature of our atmosphere. Water falls as precipitation to the earth's surface under the influence of gravity. What happens to it next?

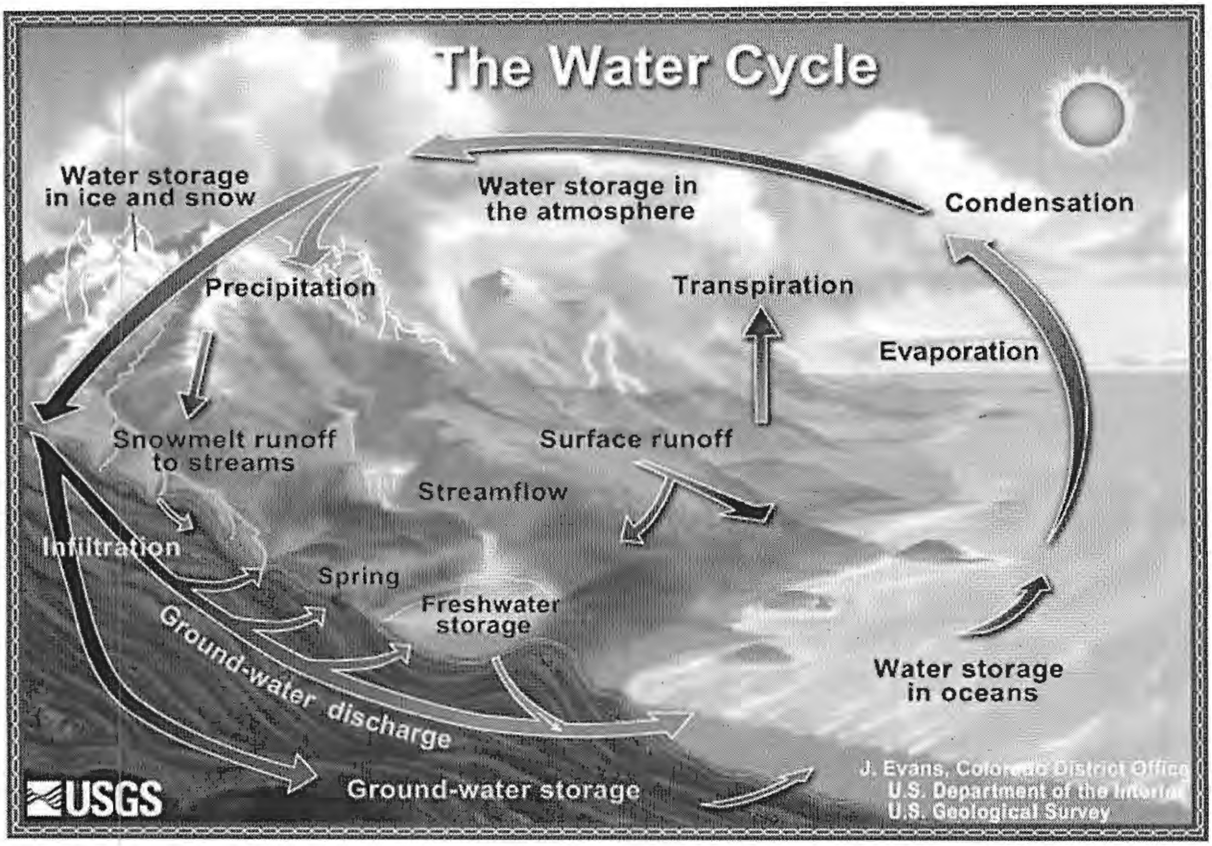


**Figure 1-8. The water cycle is fueled by energy from the sun and aided by the force of gravity. Figure is by J. Evans and is from the U.S. Geological Survey (*http://ga.water.usgs.gov/edu/watercycle.html*).**

Energy transfers occur throughout the water cycle. Shorelines are affected when the work of wind and waves moves sediment from one place to another—most dramatically during storm events.

Some of the energy input into the earth's water system does the geologic work of eroding and building beaches—in other words maintaining the shoreline system. Thus, the shorelines are high-energy, dynamic portions of the coastal system that are generally event-driven by individual storms or sets of storms and can result in massive changes within time frames of hours to years. The cumulative impact of energy from multiple storms and numerous winter storm seasons can radically change the shoreline—eroding some, building others, but always moving sediment about like chess pieces on a gameboard.

## Student Learning Cycle

**Engage:**

Class discussion: Ask students what they know about the water cycle. What are the components of the water cycle? How is energy related to the water cycle? Accept answers and state that they will learn more about the water cycle in the next activity.

**Explore:**

Materials Needed:

Slide of Figure 1-8.
Handouts of Figure 1-8 for each group
Textbooks and other print resources or Internet access

Data Table: Water Cycle Processes

| Process | Description of Process (operational definition) | Influences that Affect the Process (explain) |
|---|---|---|
| Condensation (Example) | The process by which water vapor (gas) changes into liquid (operational definition) | As the temperature decreases, molecules lose energy and slow down, causing them to move closer together. When the attraction between them is great enough, they clump together and form liquid droplets. |
| Evaporation | | |
| Transpiration | | |
| Precipitation | | |
| Surface Run-off | | |
| Ground Water Discharge | | |
| Infiltration | | |

Have students work in groups, using Figure 1-8 to answer the following questions:

1. Complete *Data Table: Water Cycle Processes* above and discuss the associated processes. An operational definition explains in everyday language what a word represents and its relationship to other concepts. You can probably devise a definition just by looking at the illustration. An example is given to help you.

2. Under what conditions might water molecules that fall to the earth as precipitation take hundreds to thousands of years to return to the atmosphere?
3. Do clouds formed over the ocean precipitate salty rain water? Explain.
4. The water cycle redistributes heat energy on earth. Explain the role of evaporation and condensation in that process.
5. How are the natural processes of evaporation and condensation related to the distillation of water?
6. Solar energy also influences the movement of air masses. Refer to appropriate reference books and explain the relationship between differential heating, movement of air masses, wind, and waves.
7. What is the relationship between the sun's energy and the movement of sand on the beach? Illustrate your answer with a diagram.

**Explain:**

Have students share and discuss the results of the water cycle activity. If there are differences, facilitate the resolution of those differences. Add to students' explanations as necessary—to enhance or correct. Have students make changes on their charts or answer sheets as appropriate. Discuss with students the role of solar energy and gravity in the water cycle. Explain the difference between "transfer mechanisms" and "reservoirs" in the water cycle. Let students help you identify transfer mechanisms (evaporation, infiltration, precipitation, run-off, etc.) and reservoirs (oceans, lakes, rivers, atmosphere, clouds, ground water, etc.).

Notes:

(1) A component that is often omitted from the water cycle is ground water, probably because it is out of sight and difficult to represent accurately.
(2) Be sure students understand the significance of differential heating.

Discuss the role of the water cycle in doing geologic work on the beaches of the Outer Banks. Explain the connection between differential heating of the earth's surface and weather.

**Extend:**

Have students diagram a possible path of energy transfer, beginning with the sun, to each of the following occurrences: (There are multiple pathways for each occurrence.)

1. ocean waves
2. precipitation in the form of snow
3. a flowing stream

**Evaluate:**

Give students a handout similar to Figure 1-8. Leave one or two blanks in each row (process, description of process, or influences that affect processes). Have students fill in missing information.

## Lesson Five: Storms and Coastal Erosion

### Background Information for Teachers:

Most shoreline erosion does not occur on a day-to-day basis, but rather is a direct product of high-energy storm events. Consequently, in any specific location erosion is a process that is extremely variable from year to year and depends upon the following climatic conditions:

1. Storm frequency;
2. Storm type and direction;
3. Storm duration and intensity; and
4. Resulting storm tides, currents, and waves

Most of the ocean shoreline, as well as the estuarine shorelines within the Northern Coastal province, are in a general state of recession. The N.C. Division of Coastal Management has documented the average annual shoreline erosion rates for the entire ocean shoreline of the state over a 52-year-period (1946 to 1998). This study established that the annual ocean shoreline erosion rates for the Hatteras and Raleigh Bay compartments varies from 0 up to an average of 16 feet/year.

Within the large, open water estuaries of the Northern Coastal province, Riggs and Ames (2003) documented average annual sediment-bank erosion rates up to -23 feet/year and marsh shoreline recession rates up -7.5 feet/year. Because there is minimal astronomical tidal fluctuation in these estuaries and the large surface areas of estuarine water or fetch (the distance that the wind blows over the water) are so great, these estuaries are dominated by storm-tide and wind-wave processes that lead to serious coastal erosion problems.

Storm winds readily push water around, blowing it out of upwind areas and piling it up against the opposite downwind shoreline as large water ramps or storm tides. This effect is illustrated in Figure 1-9. With no wind, the water surface tends to be a flat, smooth surface without waves or slope. As the wind begins to blow, waves form, and wave size increases through time. As the wind builds, the water currents begin to move in the direction of the wind, lowering the water surface in the upwind direction and raising the water surface in the downwind direction, causing flooding of the adjacent lowlands. The wind-generated waves on top of this sloping ramp, or storm tide, erode the shoreline and cause property damage to piers, roads, and land structures. The sloped water ramp will be maintained as long as there is a wind holding it up. When the wind diminishes, the water will flow back down the ramp to its original flat surface.

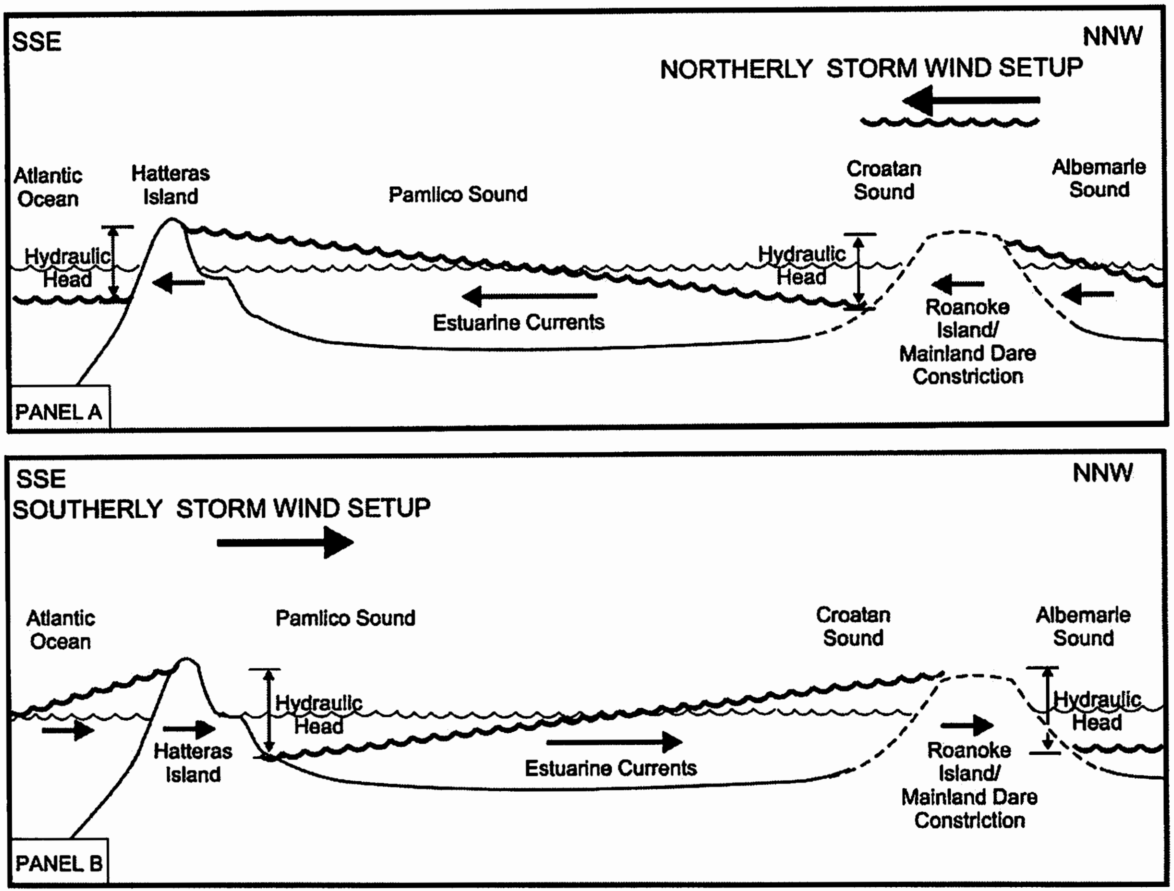


**Figure 1-9. Model of estuarine storm tides in the North Carolina sounds that form in response to different storm events. Wave energy added to both high and low storm tides is the primary process driving estuarine shoreline recession. Panel A. High storm tides occur along southern shores in response to events dominated by northeast, north, or northwest wind directions, whereas low storm tides occur along the northern shores. Panel B. High storm tides occur along the northern shores resulting from events dominated by winds from the west, southwest, or south wind directions, whereas low storm tides occur along the southern shores. Figure 5-2-1, p. 57 in Riggs and Ames (2003).**

Storm tides occur whenever a major storm associated with a weather front, tropical depression, or hurricane impacts the North Carolina coast. The resulting storm tide is dependent upon the intensity, duration, and direction of movement of each storm. Frontal storms (i.e., nor'easters) are characterized by winds that range from 25 to 50 mph, whereas tropical storms and hurricanes will typically come ashore with winds in considerable excess of this. Consequently, frontal storm tides generally range from two to five feet above mean sea level (msl), whereas tropical storms can range upwards to 10 to 15 or more feet above msl.

The direction from which strong winds blow determines where coastal flooding within the estuaries occurs (Figure 1-9). The coast on the leeward side of the water body will generally experience low water levels, whereas the windward shore will experience high water. The effects on the ocean side of the islands work the same way. As you would expect, winds from the north or northeast produce high storm tides on the shores that face north or northeast. That is the reason for the high rates of coastal erosion on the Outer Banks north of Cape Hatteras, caused by the frequent nor'easters that pummel the islands during the winter.

Hurricanes that cross the Northern Coastal province coastline in any direction produce estuarine storm tides that slosh back and forth and may impact either the inner or outer portions of the estuaries or both. The initial winds will often blow the waters up the estuaries, producing low wind tides along the sound side of the barrier islands and high wind tides in the upper reaches of the trunk estuaries. As the eye of the hurricane passes and storm winds come from the opposite direction, there is a rapid back flow, causing high water and resulting in catastrophic coastal consequences on the sound side of the barrier islands.

## Student Learning Cycle

### Engage:

State: Most shoreline erosion does not occur on a day-to-day basis, but is rather a direct product of high-energy storms—wind and waves. The specific locations where erosion occurs most dramatically vary from year to year. One important factor is the direction the storm is moving.

Show the slide of Figure 1-2. Ask students what they think the relative effect of a nor'easter would be on the following locations: (winds blowing from northeast to southwest)

1. The ocean beach along South Nags Head;
2. The sound side of Nags Head Woods;
3. The ocean beach at Avon-Buxton; and
4. The shoreline along the mainland opposite Oregon Inlet

What is the relative effect of a storm moving from southwest to northeast on the same locations?

Explain that storm winds push water around, blowing it out of one area and piling it up in the opposite direction. A sloped water ramp is actually formed and will remain as long as the storm winds hold up. Explain the meaning of the term "fetch" and show the differences between the fetch of the sounds at different locations.

### Explore:

Materials:

A handout of Figure 1-9 for each student
Slide 1-2 still projected

Have students work individually or in groups on the following questions related to Figure 1-9:

1. Now that you know the meaning of the term fetch, what connection would you think there might be between the size of the fetch and shoreline erosion?
2. Looking at Figure 1-2 on the slide, what can you infer about differences in the fetch and the potential wave size produced in the sounds by a west wind in Buxton? in South Nags Head?
3. Refer to Figure 1-9 on your handout. In Panel A, from what direction is the storm wind blowing?
4. Which shorelines of Hatteras Island and Roanoke Island are most likely to erode from the waves produced by these winds?
5. In Panel B, from which direction is the storm wind blowing?

6. Which shorelines of Hatteras Island and Roanoke Island are most likely to erode from the waves produced by these winds?

**Explain:**

Have students discuss their answers to the questions related to Figure 1-9. They may have had difficulty in knowing how to label areas such as the Pamlico Sound side of Hatteras Island or the Croatan Sound side of Roanoke Island. If they show you the area affected, help them with appropriate descriptive phrases that will not be confusing.

Explain why a large fetch results in greater wave energy, referring back to question #2 related to Buxton and South Nags Head. You might mention Hurricane Emily that came in along the Buxton area as a fairly mild hurricane, but the large fetch of the Pamlico Sound allowed the build-up of huge waves. When the wind died down, the ramp of water that had piled up against the mainland shoreline surged back onto the sound side of Buxton, flooding homes and businesses on that side of the island. Cape Hatteras School had water above the computer monitors in the computer lab.

The main ideas of this lesson are these:

- Storms play a key role in the erosion of shoreline (including ocean, soundside, and mainland) along the Outer Banks.
- The size of the fetch across which storm winds blow affects the size of the waves that hit the shore.
- The direction of the storm determines the direction of the buildup of water that causes major erosion of shorelines.

**Extend:**

Have students choose a hurricane from North Carolina's history and find out all they can about it, including its size, the direction of its winds, the effect on the shorelines (ocean, sound, and mainland), and any other pertinent facts.

**Evaluate:**

Provide students with a copy of Figure 1-2 with several shorelines marked (mainland, soundside, oceanside). Have students record their predictions of the effect of a nor'easter on shoreline erosion at each of those locations.

## Lesson Six: North Carolina Coastal Plain—Surface Water Dynamics

Background Information for Teachers:

Figure 1-10 is a map of North Carolina with an overlay of the drainage basins. A vast and complex network of creeks, streams, and rivers move surface water off the uplands of the Appalachian, Piedmont, and Coastal Plain provinces towards the Atlantic Ocean. The drainage basins (outlined in red) are the regions whose run-off ends up in the rivers for which they are named. Many smaller streams also collect run-off from rain and carry it into the larger rivers and ultimately to the ocean.

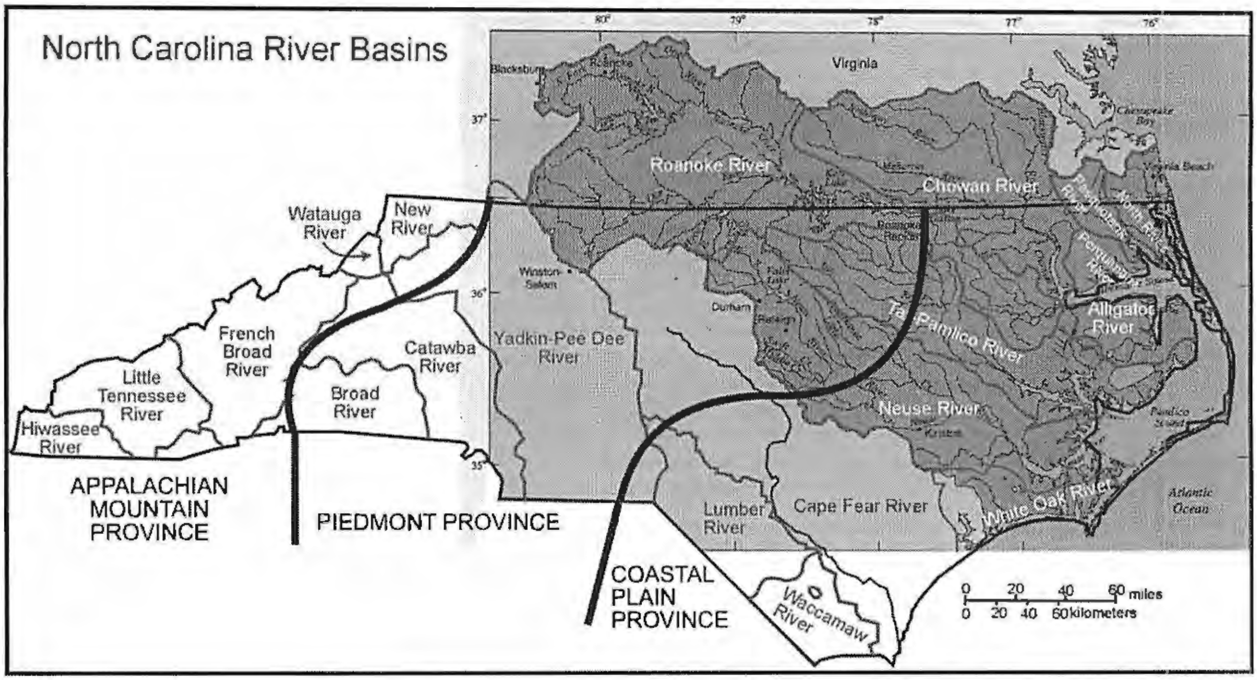
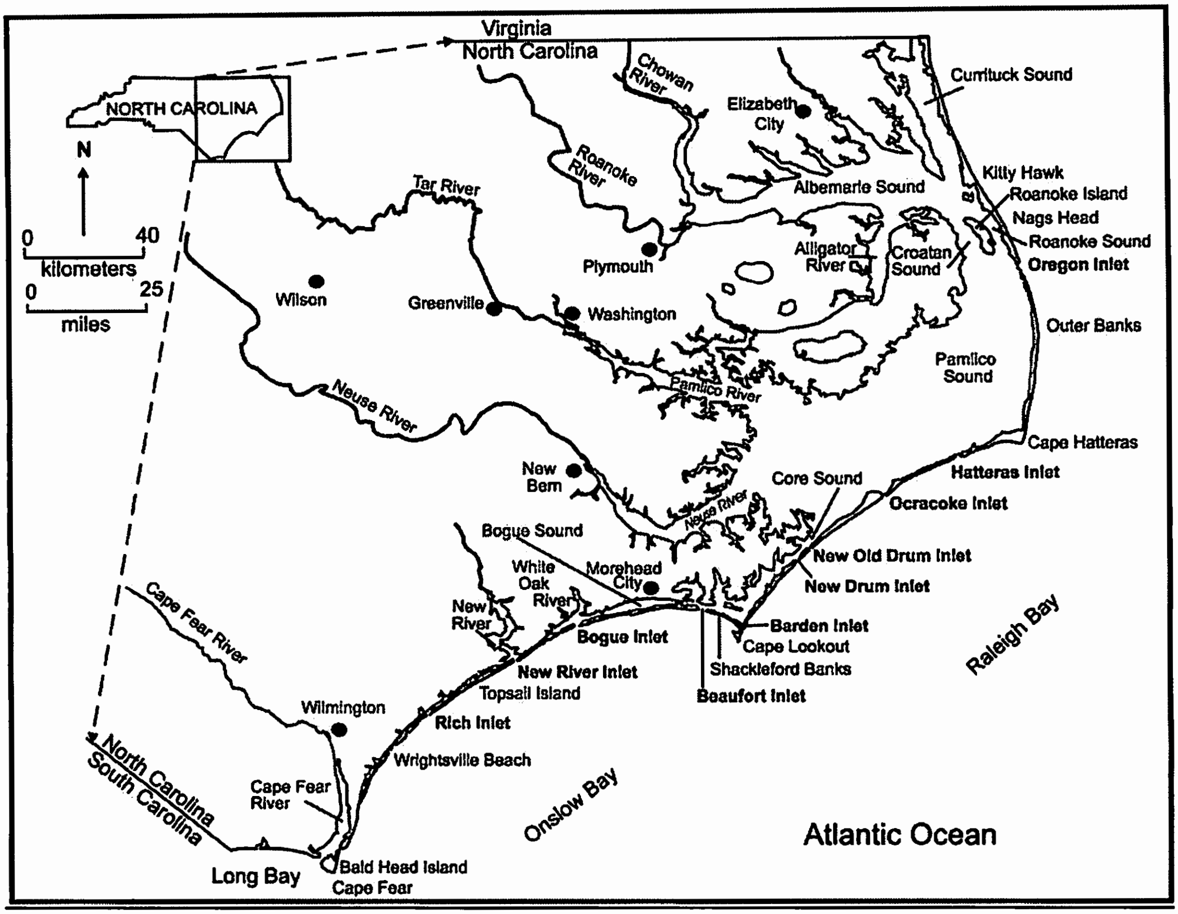


**Figure 1-10. Map of the three geologic provinces (outlined in black) and drainage basins (outlined in red). The river basins underlain by green color and with the blue drainages drawn in, flow to the Atlantic Ocean and produce the vast northeastern North Carolina coastal system. Figure 2-1-1, p. 17 in Riggs and Ames (2003).**

As the rivers that flow to the Atlantic Ocean approach sea level, a broad, low-sloping transition zone forms and connects the rivers to the ocean. This transition zone is called the estuarine system. Where the river's bottom drops below sea level, the river valleys become flooded and produce the drowned-river estuarine system. Thus, the estuaries occur between the freshwater river drainage system and the saltwater oceanic system, which are separated by the barrier island chain. The barrier islands function as a sand dam with a few inlets or outlets that allow the ultimate escape of fresh water into the Atlantic Ocean and the mixing of some ocean salt water into the estuaries. Thus, the estuaries are great mixing basins of fresh and salt water within the coastal zone. Figure 1-11 shows North Carolina's coastal zone with major towns and coastal features labeled.



**<u>Figure 1-11.</u> Location map shows major towns and coastal features for the North Carolina coastal system. Figure 2-1-2, p. 18 in Riggs and Ames (2003).**

<u>Student Learning Cycle</u>

**<u>Engage:</u>**
Show students a slide of Figure 1-10. Explain that the figure shows the three geologic provinces of North Carolina and the drainage basins. Have students locate the approximate location of your school on the map and to identify the river basin in which the school resides. Ask students where water that falls within your drainage basin eventually ends up.

**<u>Note:</u>** Students will probably see the flow of the rivers to the Atlantic Ocean. Ask: Does all of the water make it to the ocean? If not, where might it go? (Look for answers that reinforce students' understanding of the water cycle.)

**<u>Explore:</u>**
<u>Materials Needed:</u>
Handout of Figure 1-10 for each group
Handout of Figure 1-11 for each group
Rulers

Directions for student groups:

Use Figure 1-10 to help you answer the following questions:

1. Find Cape Hatteras on Figure 1-10. Using a ruler and a pencil, draw a horizontal line across the figure from Cape Hatteras to the westernmost border of North Carolina.
2. Using the scale located on Figure 1-10, (a) determine the width along this line of each of the three provinces. (b) Which province is the widest? (c) Which is the narrowest?
3. Define drainage basin. In what province and drainage basin is your school located?
4. Select a drainage basin in the northeast other than the one in which your school is located. If it rains in that basin, into what major river does the surface water eventually flow?
5. Name the major rivers (Figures 1-10 and 1-11) that contribute fresh water to Albemarle and Pamlico Sounds.

Use Figure 1-11 to help you answer these questions:

6. List the inlets along the Outer Banks between Cape Lookout and the Virginia line (Figure 1-11) that allow fresh water out and seawater into the estuary.
7. How many inlets occur between Cape Lookout and Cape Hatteras and north of Cape Hatteras (Figure 1-11)?
8. What differences in the saltiness of the sound waters would you predict between the Albemarle and Pamlico Sound systems? Explain.

**Explain:**

Have student groups share their answers. Spend time on question 8, helping students to understand the role of inlets in allowing the influx of ocean water into the sounds and the resulting salinity at different points within the system. Use the teacher background information to discuss the drowned-river estuarine system, the barrier islands, and the role of the estuaries as great mixing basins of fresh and salt water, providing a unique habitat for many species of plants and animals that thrive in such an environment.

**Extend:**

Conduct a class discussion on the effect of major storm events that bring large amounts of rain across the coastal plain (e.g. Hurricane Floyd). Refer back to Figure 1-2 and ask these questions: What do you think the effect of Hurricane Floyd was on the salinity of the Pamlico Sound? What effects do you think the run-off of soil had on the Pamlico Sound? What kinds of materials are carried along with soil when heavy rains produce run-off into the sounds?

**Evaluate:**

Have students use Figure 1-10 as they consider this scenario: Rain falls on the school yard tomorrow. List as many possibilities for the distribution of those water molecules over the next year as you can. Consider information about river basins and the water cycle in providing your answers.

## Lesson Seven: North Carolina Coastal Plain Province

Background Information for Teachers:

Figure 1-12 is a generalized geologic map of the N. C. Coastal Plain, suggesting the major differences that occur between the northern and southern coastal regions. These differences in the underlying geologic framework reflect different and unique geological heritages that result in distinctive types of barrier islands, inlets, and estuaries. A line drawn from Raleigh through Kinston and Cape Lookout separates the coastal system into the Northern and Southern Coastal provinces. The unique topography of the North Carolina barrier islands is partly controlled by the width, bathymetry (depth of the ocean floor from the water surface), and geologic composition of the adjacent continental shelf and the drainage basin topography of the coastal plain that is being flooded. Notice in Figure 1-12 that the North Carolina coast consists of a series of cuspate bays or coastal compartments, each with different spatial orientations and geologic character of the adjacent continental shelf. (Note: Cuspate refers to the points that define the bays. Think of bicuspids or tricuspids—teeth with two or three points.)

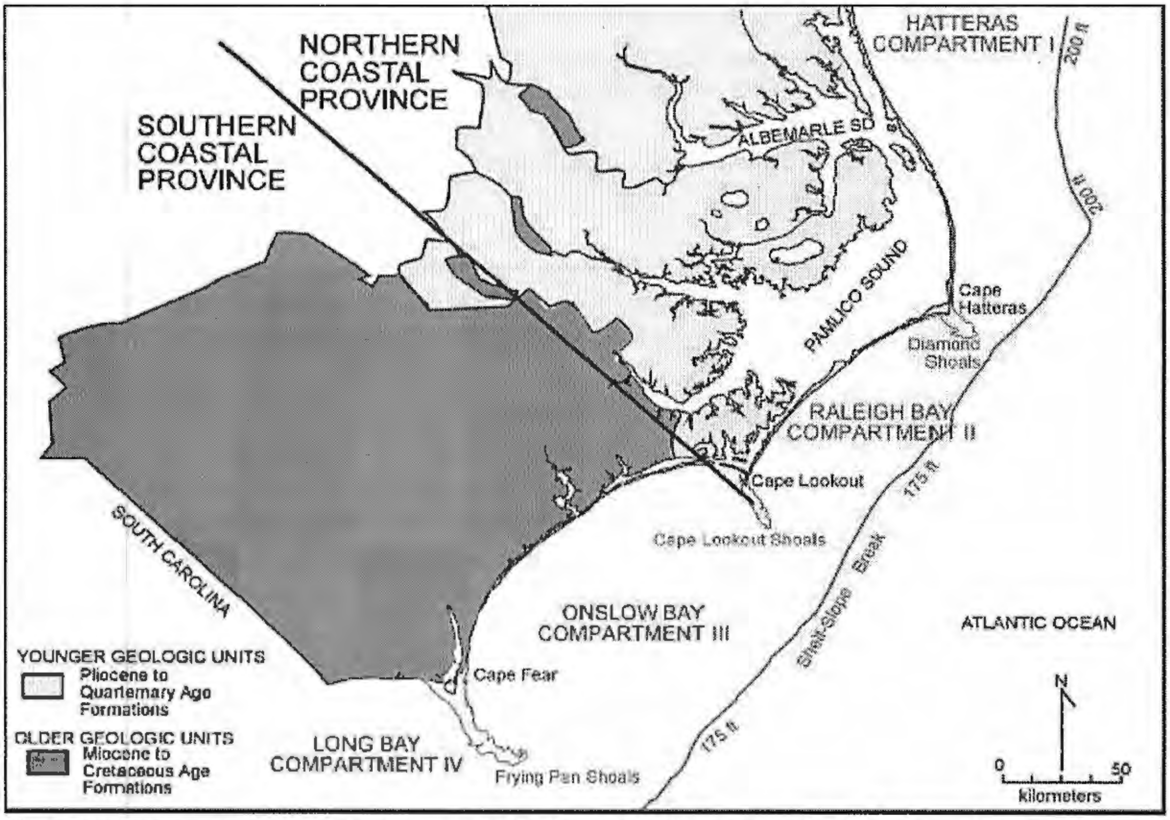


**Figure 1-12. Generalized geologic map of the North Carolina Coastal Plain shows the two coastal provinces and four geomorphic compartments of the coastal system. Geologic outcrop patterns are summarized from the *Geologic Map of North Carolina* (NCGS, 1985). Figure 2-2-1, p. 21 in Riggs and Ames (2003).**

The Northern Coastal province is characterized by the following:

1) long barrier islands;
2) few inlets within the islands (today only five inlets); and

3) an extensive sequence of *drowned-river estuaries* that form the vast Albemarle-Pamlico estuarine system.

The northern barrier islands project seaward, forming the famous Cape Hatteras and associated Outer Banks—a sand dam that semi-isolates the Albemarle-Pamlico estuarine system from the ocean.

The floor of the continental shelf in the Hatteras and Raleigh Bay compartments consists primarily of younger geologic units that are Pliocene and Pleistocene in age. These units are composed of moderately soft mudstone, sandstone, fossiliferous gravel and sandy limestone. There are local areas covered with variable thicknesses of modern unconsolidated sand. The continental shelf in the Hatteras compartment is relatively deep and becomes extremely narrow at Cape Hatteras, allowing much larger waves to interact directly with the beach, particularly at Cape Hatteras. The Raleigh Bay compartment is relatively narrow, but is not as deep as the area north of the Cape. Thus, it generally tends to have intermediate size waves that interact with the beach.

The continental shelf off of the Onslow and Long Bay compartments consists primarily of older geologic units that range from Cretaceous to Pliocene in age. These units are composed of relatively hard mudstone, sandstone, and limestone with very little modern unconsolidated sand. Because of the harder rock composition, the continental shelves in both compartments are very wide and shallow, causing the general wave patterns to be much smaller than the northern two compartments.

In summary, the Northern Coastal province generally has significantly higher wave energy than the Southern Coastal province. Here is the connection.

1. In the Northern Coastal province, the continental shelf is generally narrower and deeper than that of the Southern Coastal province, resulting in higher wave energy at the Cape Hatteras shore. This is the reason surfers flock to this site. Wave energy is greater at Hatteras because there is deeper water all the way to the shoreface and less distance over which the open ocean waves lose energy by dragging along the deeper bottom.

2. Conversely, wave energy in the Southern Coastal province is generally less because of the greater distance from the shelf's edge and the much shallower character of the shelf. This causes an increased loss of energy as waves drag along the shallow bottom over longer distances.

The shoals associated with each of the capes in Figure 1-12 consist of extensive sand deposits that are perpendicular to the shore and extend seaward for the following approximate distances:

10 miles (Diamond Shoals off Cape Hatteras)
15 miles (Lookout Shoals off Cape Lookout)
30 miles (Frying Pan Shoals off Cape Fear).

These vast, shallow-water shoal systems often have water depths less than 10 feet over large areas and are extremely treacherous for ships. These shallow shoals have caused the demise of many mariners and have given the North Carolina coast the dubious honor of being called "the Graveyard of the Atlantic."

Three types of storms frequently affect the barrier islands: 1) The winter storms or nor'easters have strong NE winds; 2) The summer storms or sou'westers have strong SW winds; and 3) Tropical storms and hurricanes originate in the warm ocean waters near the equator and often approach N.C. from the S to SE, primarily during the summer and fall.

## Student Learning Cycle

**Engage:**

Show a slide of Figure 1-12. Ask: What differences do you see offhand between the Northern Coastal province and the Southern Coastal province? In your exploration, you will examine this figure more closely to identify features of each.

**Explore:**

Materials:

Slide of Figure 1-12

One handout per group of Figure 1-12

Directions for student groups:

Use Figure 1-12 to help you answer these questions:

1. List three characteristics of the Northern Coastal province that differ from the Southern Coastal province.
2. What are the three capes that dominate the North Carolina coast (Figure 1-12)?
3. From your observation of the figure, what do you think capes are? What is the physical relationship between the capes and the adjacent sand shoals?
4. The cape shoals that occur off the three capes in North Carolina are called the "Graveyard of the Atlantic." Why?

**Explain:**

Use student responses to initiate a discussion of the differences between the Northern Coastal province and the Southern Coastal province. Use the data table on the next page to characterize the different compartments. Students can help fill in parts of the chart by referring to Figure 1-12. You will have to provide information for other parts. The data will become part of students' notes.

**Extend:**

Provide documentation about hurricanes that have struck the North Carolina coastline. Ask students to look at the direction of hurricane winds. How did the direction of the hurricane winds relate to erosion of shorelines? How were the islands and mainland shorelines affected differently in the Northern Coastal province and the Southern Coastal province? Explain.

**Evaluate:**

Write a paragraph listing differences between the Northern Coastal Province and the Southern Coastal Province. Cite reasons for those differences.

Data Table

| | Hatteras Compartment | Raleigh Bay Compartment | Onslow Bay Compartment | Long Bay Compartment |
|---|---|---|---|---|
| Direction the coast faces | | | | |
| Type of storms that most frequently affect the coast | | | | |
| Width of the continental shelf | | | | |
| Age of rocks forming continental shelf | | | | |

Explain why wave energy is greater in the north than in the south. Why is Cape Hatteras a destination for surfers?

## Lesson Eight: Barrier Islands

### Teacher Background Information:

On the eastern side of the estuarine zone is a narrow strip of islands that act as a dam between the estuaries and ocean (Figures 1-2 and 1-11). They are called barrier islands because they are separated from the mainland by major water bodies.

This extensive strip of sand islands was produced by the interaction between high-energy ocean storms and the low-sloping coastal plain. As you saw in Figure 1-11, the sand dam is broken by a series of small openings commonly called inlets or outlets. However, barrier islands are like icebergs, with only a small portion rising above the sea surface and the greatest portion hidden below sea level. The barrier island is perched on the top of a foundation called the shore face, which slopes steeply to between 25 to 70 feet below sea level. The ocean bottom then flattens onto the inner continental shelf (Figure 1-13), the underwater or drowned portion of the coastal plain. The ocean side of a barrier island functions as an important energy-absorbing surface for wave, tidal, and current energy along the ocean margin.

On the Outer Banks, barrier islands can be divided into two basic types. A simple overwash barrier island occurs in a section of the coast where there is little sand available to form the island (Figure 1-13A). These islands are sediment starved and have relatively low elevations and narrow widths. Complex barrier islands are sediment rich with abundant sand available to form a wide and high island with tiers of beach ridges and dunes stretching back from the ocean front (Figure 1-13B). Natural barrier island processes will affect simple overwash islands differently than wide complex barrier islands as indicated in the aerial photographs of Pea Island (Figure 1-14) and the effects of Hurricane Isabel on Hatteras Island (Figure 1-5).

Storms are important in maintaining the barrier islands. Ocean waves erode beaches and produce overwash that builds barrier island height and width. The upper panel in Figure 1-14 shows a major overwash in which the energy of Hurricane Isabel transported large quantities of sand from the ocean side across the island all the way to the sound side. This event demonstrates the natural process of island building, in which overwash adds height to the island and builds the sound-side shore that becomes the new back-barrier marsh ecosystem. In addition, storms open inlets in weak portions of the barrier and build flood-tide deltas into the estuary with the eroded sands from the barrier. This adds width to the back side of the barrier upon which the barrier can migrate upon through time (Figure 1-15). Over a long period of time as the ocean shoreline continues to erode and recede, the overwash and inlet processes cause the island to gradually roll over itself, slowly moving toward the mainland.

A high and wide barrier island contains large volumes of sand in the form of beach ridges and back-barrier dune fields that prevent inlets from forming and overwash events from flowing over the island. Examples include Kitty Hawk Woods (Figure 1-16), Nags Head Woods, Jockey's Ridge, and Buxton Woods. Small-scale overwash occurs only locally along the active beach zone.

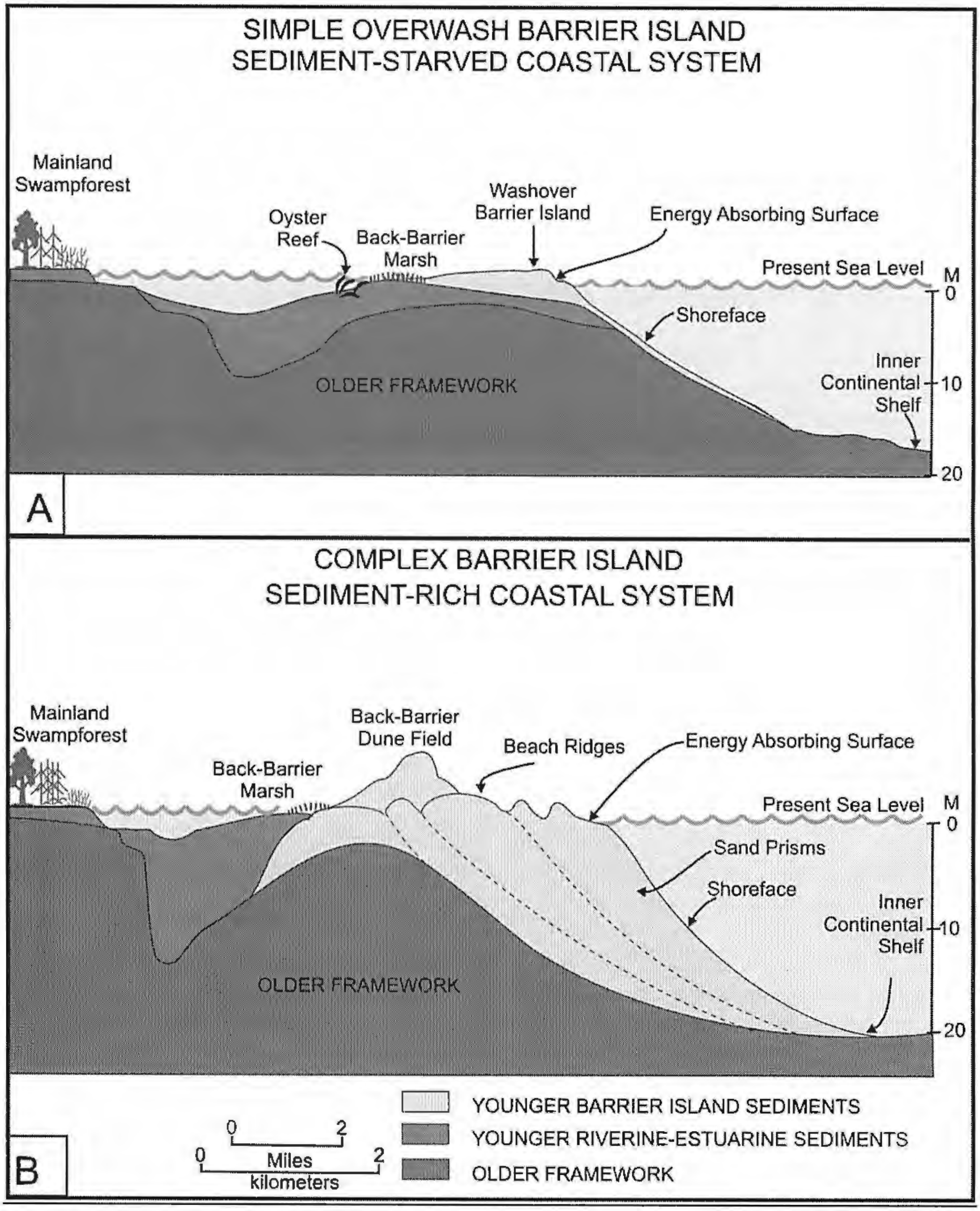


**Figure 1-13.** Schematic cross-sectional diagrams show a simple overwash (Panel A) and complex barrier islands (Panel B) and the associated back-barrier estuarine shorelines. The older framework sediments on the Outer Banks are Pleistocene in age (> 10,000 years), while the younger sediments are all Holocene in age (< 10,000 years). Figure 4-5-1, p. 50 in Riggs and Ames (2003).

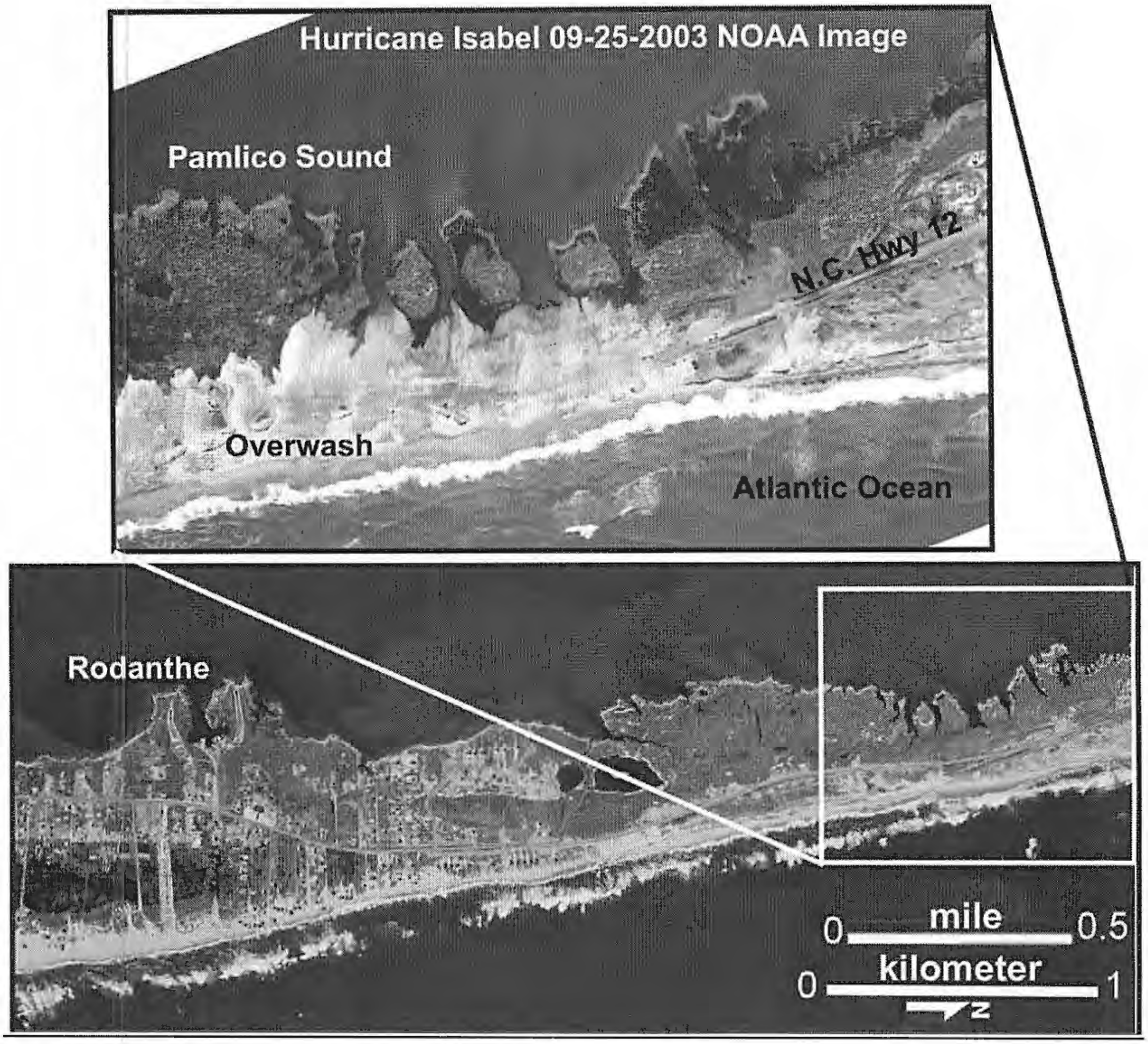


Figure 1-14. Pea Island aerial photographs show a segment of simple overwash barrier island just north of Rodanthe. The bottom panel is a 1998 aerial photograph of Pea Island with a box indicating the area in the NOAA 2003 post-Hurricane Isabel aerial photograph in the upper panel. Hurricane Isabel caused extensive overwash that buried N.C. Hwy. 12. The overwash sands add critical elevation to the barrier and width if the overwash sands are carried across the island to the estuarine side. Many houses in north Rodanthe were either destroyed or severely damaged in this storm.

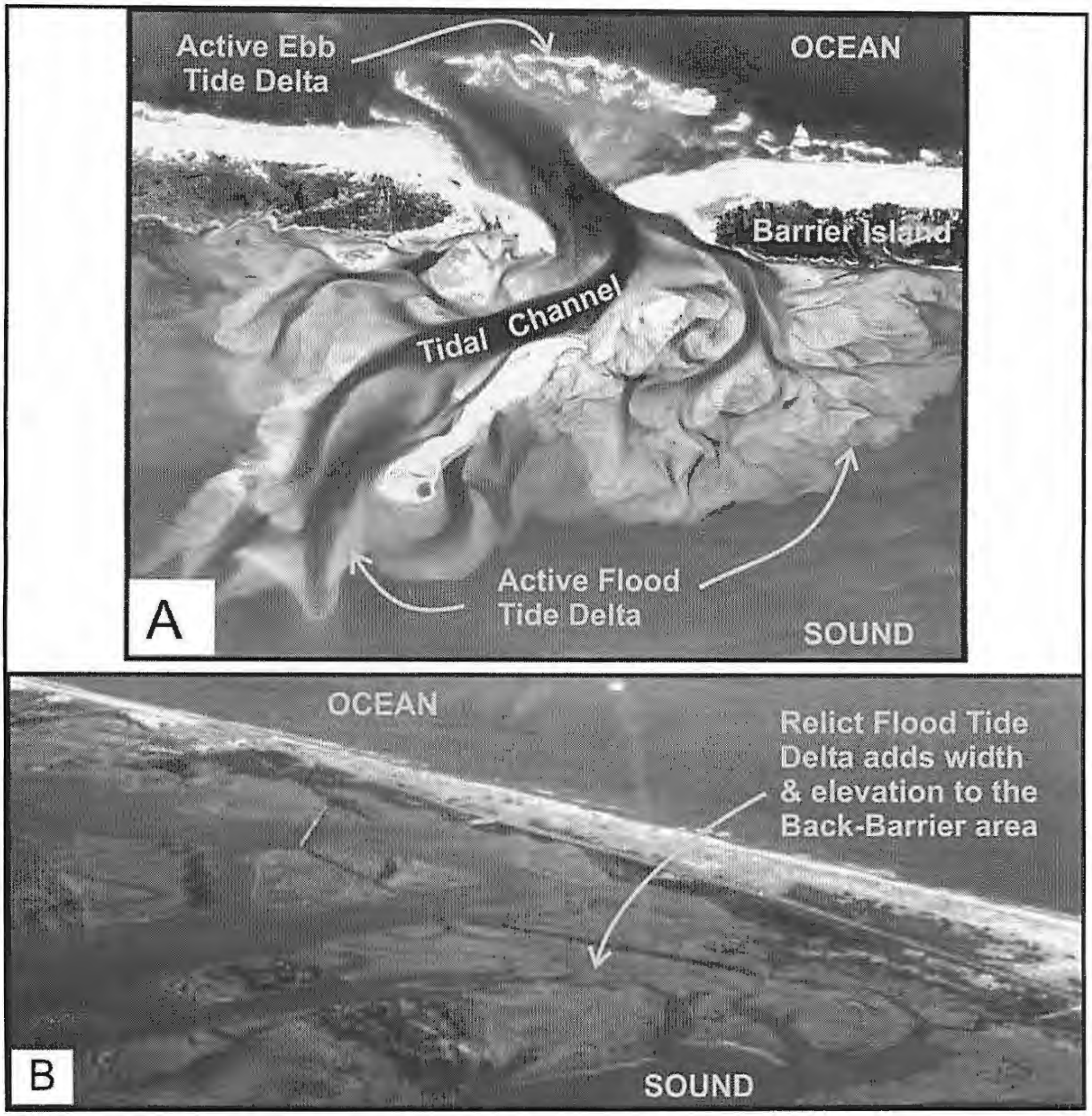


**Figure 1-15**. **Panel A**. The 1943 aerial photograph of Drum Inlet shows the separation of North and South Core Banks with extensive sand shoals associated with the tidal deltas. The ebb tide delta forms on the ocean side and the flood tide delta on the sound side of the barrier island. The deltas are formed by the deposition of sand sediment when the strong inlet tidal currents transporting the sand enter the adjacent ocean and estuarine water bodies. **Panel B**. This is a 1992 oblique aerial photograph of New Inlet flood-tide delta. The inlet closed in 1945 and all sand shoals have subsequently become vegetated by salt marshes. Notice the historic New Inlet Bridge that is still visible across the marsh.

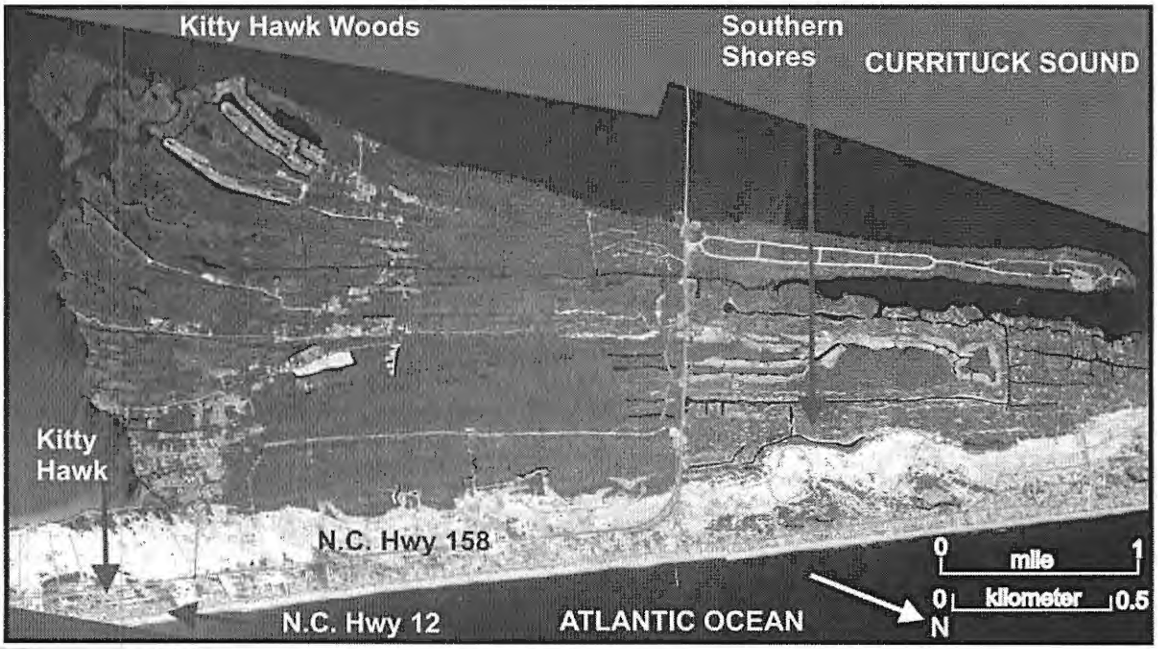


**Figure 1-16. A 1982 infrared aerial photograph of Kitty Hawk shows the extensive sequence of beach ridges that constitute Kitty Hawk Woods. This is an example of a complex barrier island. The red color in this false color image taken in the winter, is photosynthesizing plants (e.g. pines, bay trees, live oaks etc.), whereas the gray-green color represents the marsh grasses. The white zone west of N.C. Hwy. 158 is a series of slightly developed back-barrier dunes, whereas the white zone east of N.C. Hwy. 158 is the highly developed active beach. Figure 4-5-3, Panel A, p. 52 in Riggs and Ames (2003).**

## Student Learning Cycle

**Engage:**

Show a slide of Figure 1-13. Point out major differences between a simple overwash barrier island and a complex barrier island. Be sure to mention these points:

- A simple overwash barrier island occurs in a section of the coast where there is little sand available to form the island. These islands are "sediment-starved" and have relatively low elevations and narrow widths.
- A complex barrier island has abundant sand available ("sediment-rich") to form a wide, high island, with tiers of beach ridges stretching a great distance from the ocean front.

Have students discuss what differences might occur between the two types of islands when storm winds approach from the ocean side.

Show a slide of Figure 1-2. Ask students to identify a section of the Outer Banks that would be an example of a simple overwash barrier island. Ask them to identify a section that would be a complex barrier island.

Show a slide of Figure 1-5. Ask students to speculate on what happened to the sand that once formed the barrier island where Isabel Inlet was formed by Hurricane Isabel as it crossed the barrier island in the vicinity of Hatteras Island.

**Explore:**

Materials Needed:

Handout of Figures 1-14 and 1-16

Have student groups discuss and record responses to the questions below.
Isabel Inlet represents a classic conflict between natural dynamics and human economic utilization of the barrier islands.

1. Why was Isabel Inlet closed and N.C. Hwy. 12 rebuilt within five weeks after the storm opened it?
2. Why are inlets important to the health of a simple overwash barrier island?
3. How are these two functions (#1 and #2) in conflict with each other?
4. Oysters live in the estuary on the back side of the barrier island. However, they are the most common shell on the ocean beach in front of simple barrier islands. Explain how the estuarine oyster shells get onto the ocean beach (Figure 1-13A).
5. Identify a major conflict and human inconvenience caused by storm overwash in the aerial photographs in Figure 1-14. How do you think the N.C. Department of Transportation deals with this problem?
6. Why does the N.C. Department of Transportation move overwash sand from the sound side of the highway back onto the ocean side? What are the long-term consequences of this for a simple barrier island that continues to erode on the ocean side?
7. What alternatives might be considered to accommodate the transportation needs of island residents and visitors without disrupting the natural evolution of the island?
8. Using the scale on both photos (Figures 1-14 and 1-16), measure the island width at the widest part of the Pea Island and Kitty Hawk barrier island segments.
9. From what you know about simple overwash barrier islands and complex barrier islands, describe the differences between the Kitty Hawk barrier island segment (Figure 1-16) and the Pea Island barrier island segment (Figure 1-14).

**Explain:**

Use student responses to the "explore" phase as a basis for classroom discussion. Reiterate the differences between the two types of barrier islands with an emphasis on the differences in how they respond to storm events. A major concept in this section is the importance of storms in island building—the natural process of washing sand to the sound side and building up the island in that direction. Islands gradually role over themselves toward the mainland. This is the reason for finding oyster shells on the ocean side. This is a good place to introduce the idea of conflicting interests in any environment—and the importance of using evidence in making decisions—including scientific evidence, but also economic and cultural realities. Decision-making will be a major emphasis in *Part 2.*

**Extend:**

Have students discuss this question: If you were planning to buy a lot for a house on the Outer Banks, how would your knowledge of barrier islands help to inform your decision? Propose this hypothetical scenario. Have student groups choose a community along the Outer Banks where they might like to buy property. Have them do research to determine the history of that community in terms of storm damage and shoreline erosion. There are Internet sites that provide that information. Have students weigh the pros and cons for their proposed sites and make a decision about the purchase.

**Evaluate:**

Write answers to the following questions:

1. What are differences between complex barrier islands and simple overwash barrier islands?
2. Explain this statement: Storms are very important in the process of island building.
3. What is the short-term advantage of moving sand that has washed across a simple overwash island back to the ocean side?
4. What is the long-term disadvantage?

## Lesson Nine: Role of Barrier Islands and Their Inlet/Outlet Systems

### Teacher Background Information:

North Carolina's barrier islands act as a large sand dam, separating the open waters of the Atlantic Ocean from the semi-enclosed waters of the estuarine system. The string of sand barriers, built and maintained by the higher energy levels of the oceanic system, serve as an energy buffer, largely protecting the back-barrier estuarine system from extremely high-energy oceanic conditions.

Associated with barrier islands are small holes through the sand dam known as inlets that historically have allowed shipping of goods and movement of people (Figures 1-2 and 1-11). Inlets are more appropriately called "outlets" because their main function is to allow riverine fresh water that flows off the land to pass through the barrier island sand dam and discharge into the ocean, which is the ultimate base level. However, once an outlet is open, then it also functions as an inlet, because astronomical tides create water level differentials resulting in active tidal exchange of ocean water through inlets and into adjacent estuaries. The regularity and strength of tidal currents produced by this tidal pumping maintains an inlet/outlet system on the *short-term scale* of hours to years. Storm pumping, resulting from major storm tide events, maintains an inlet/outlet system on the *longer-term scale* of years to centuries.

Thus, there are two sources of water that feed the estuarine system.
1. Gravity causes fresh water in rivers to flow downhill into the estuaries and ultimately into the oceans.
2. Ocean water is pumped through the inlets by astronomical and storm tides.

Consequently, estuaries act as great mixing basins where the two water masses intermix to form the following general salinity gradients.
1. Fresh water in the upstream or riverine portions,
2. Low-brackish water in the inner estuaries,
3. High-brackish water in the outer estuaries and inlets, and
4. Normal sea water salinity in the offshore oceanic regions.

The interplay between the regularity of astronomical tides, irregularity of wind tides, and vast array of brackish waters characterizing the estuarine system largely determines what coastal plant and animal communities occur within the estuarine systems and where they thrive.

### Student Learning Cycle

**Engage:**
View a slide of Figure 1-11. Discuss as a class the areas in the Pamlico and Albemarle Sounds that are most likely characterize by:
(1) fresh water
(2) low-brackish water
(3) high-brackish water
(4) sea water

Consider distances from rivers and inlets.

**Explore:**
Groups continue to use the slide of Figure 1-11 to answer these questions:

1. What do you think the impact of major storm events would have on the salinity patterns in the estuaries that you discussed previously? Consider two different kinds of storms: an ocean storm surge vs storm flooding on the mainland (upland).
2. What do you think the impact of seasonal climate fluctuations (dry seasons with low river flow vs. wet season with high river flow) would be on the salinity patterns in the estuaries that you identified before.
3. Conduct a library or Internet research project to learn about the role of estuaries as nurseries for marine life.

**Explain:**

Use the student exploration as a basis for discussion, providing additional information found in the Teacher Background Information. Major concepts: factors that affect salinity in the estuaries and the role of estuaries as nurseries for marine life.

**Extend:**

Choose from among these assignments as an extension for individual students:

1. Find good reference books on plants and animals in the coastal region and identify a series of plants and animals that are specifically adapted for living in (1) fresh water, (2) low-brackish water, (3) high-brackish water, and (4) sea-water habitats.
2. Do a library/Internet research project on the effects of sudden changes in salinity upon the plant and animal communities that live in the estuaries.

**Evaluate:**

Explain this statement: Estuaries act as great mixing basins.

## Lesson Ten: Back-Barrier Sounds of the Northern Coastal Province

### Teacher Background Information:

The back-barrier sounds of the Northern province (Figures 1-2 and 1-11) are medium to large estuaries that are parallel to the coast. They include:

1. Currituck Sound in the north,
2. Roanoke and Croatan Sounds separated by Roanoke Island,
3. Pamlico Sound, the largest estuary, and
4. Core Sound in the south.

As seen previously, only five inlets exist in more than 190 miles of barrier islands, limiting the influence of oceanic water and processes to this estuarine system. In addition, there is a major input of fresh water from both Piedmont and Coastal Plain draining rivers. These factors result in an estuarine system with minor and small astronomical tides and highly variable salinities that range from fresh water to high-brackish water within specific portions of these large water bodies.

However, because the sounds behind the Outer Banks have relatively large surface areas with moderately uniform depths and no interior salt marshes, there is maximum response to waves and wind tides. Normal wind tides generally are small (inches to 1-2 feet) with storm-tide heights (amplitudes) commonly up to 3 to 5 feet and occasionally up to 10 feet or more in response to major hurricanes.

As illustrated by Figure 1-9, the direction, intensity, and duration of wind determine the currents and tide levels. For example, a nor'easter that blows strongly for several days produces strong south-flowing currents. This will blow much of the water out of Currituck, Roanoke, and Croatan Sounds (with 3 to 5 foot lower water levels) and produce flood conditions in southern Pamlico and Core Sounds (with 3 to 5 foot higher water levels). (Refer to Figure 1-11.) This sloped water surface will hold as long as the wind continues to blow. As soon as the wind relaxes in intensity or shifts direction, the water flow responds immediately. Consequently, these back-barrier sounds tend to be dominated by irregular flooding and wind tides caused by storms.

### Student Learning Cycle

**Engage:**
Show a slide of Figure 1-11. Have students identify the five back-barrier sounds located in the Northern Province. Which is the northernmost? Which two are separated by Roanoke Island? Which is the largest? Which is the southernmost?

**Explore:**
Materials Needed:
Handout of Figure 1-11 (one per group)
Rulers

1. Using Figure 1-11, estimate the widths of each of the five sounds at the widest point (use the scale found on the figure).
2. If a nor'easter blows strongly for several days, in which direction do you think storm currents in the sounds will flow?
3. In which sounds will the water level be lower?
4. In which sounds will the water level be higher? (more likelihood of flooding)

5. Why do you think inlets might also be called outlets?
6. What forces move fresh water down the rivers into the sounds and ocean water through the inlets into the sounds?

**Explain:**

Discuss student answers to the questions and reconcile differences among groups.

**Extend:**

Set up a chart for the classroom that includes all the variables associated with the impact of storms on the barrier island and estuary systems. Keep a daily/weekly record of storm warnings and watches for the coastal area over the course of the semester/year. Document the direction, intensity, and duration of the wind; the water level response in the form of tide level and storm surge at several different locations within the coastal system; the amount of precipitation; and the coastal areas that flood. Much of this information can be retrieved from the National Weather Service Web site (http://www.weather.gov/). With each storm, discuss how the impacts are consistent with your predictions.

**Evaluate:**

Using a slide of Figure 1-11, explain why a hurricane moving east to west across Pamlico Sound might cause more damage on the mainland than one moving east to west across Currituck Sound.

## Lesson Eleven: The Shoreline, Shore Zone, and Beach

Teacher Background Information:

The Shoreline. In geometry, the intersection of two planes in space forms a two dimensional line. Likewise, wherever a water surface intersects the land surface, there is a line that is called the shoreline (Figure 1-17). However, the land surface is generally quite irregular, resulting in an irregular shaped shoreline. Also, the water surface is rarely flat or perfectly horizontal. Rather it fluctuates continuously causing the shoreline to move up and down and produce a shore zone that extends over some area determined by the geometry of the adjacent land surface.

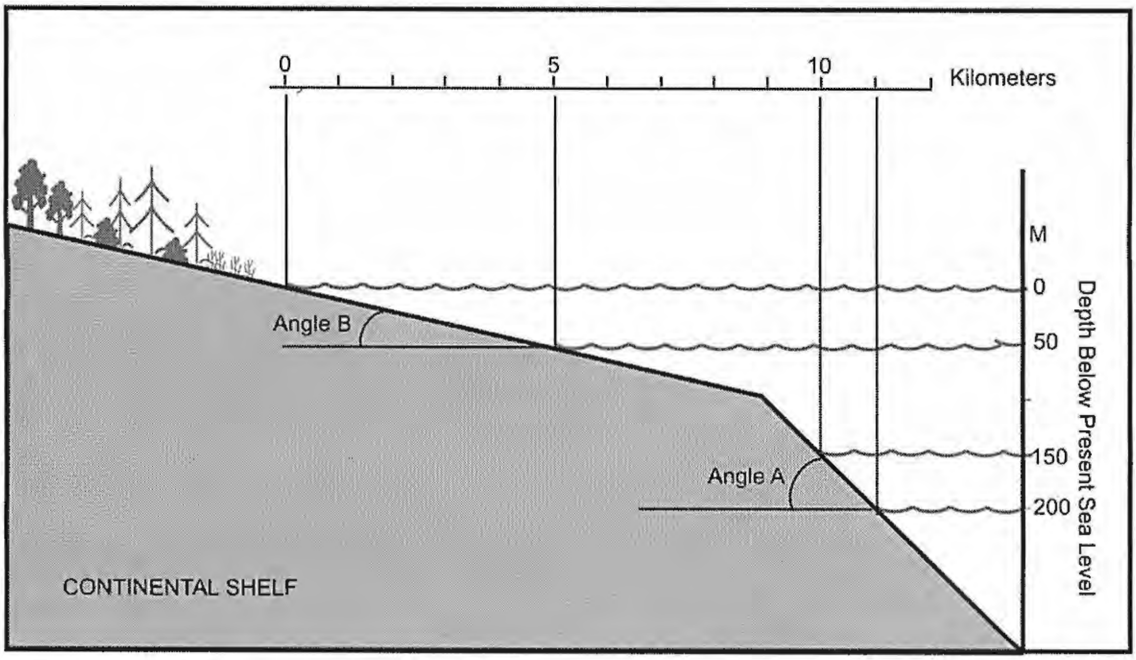


**Figure 1-17. This figure shows the point of intersection between the sloping land surface and the horizontal water surface. The intersection of these two planes forms a shoreline that will move as water level changes in response to either an increase or decrease in water volume or changes in the water level due to astronomical tides, wind tides, and storm surges such as illustrated in Figure 1-9.**

Development of the Shore Zone. The wave and tidal regimes of each coastal segment dictate the actual shore zone, which consists of a series of many shorelines that move up and down continuously on short-term time scales (i.e., hours to seasons). Any given coastal segment contains low and high astronomical tide shorelines, normal storm tide shorelines, and supra-storm tide shorelines. A continuum of shorelines exists in between each of these end member shorelines because the changes are gradual through some time period. If the land surface is characterized by a low slope, the shore zone tends to be broad. However, if the land has a relatively steep slope, the shore zone tends to be narrow (Figure 1-18).

The surface of any water body is not static, but rather it is extremely dynamic as it responds to many different forces through time. The water surface oscillates in response to short-term astronomical, wind, and storm tides, as well as long-term changes in global sea level. Astronomical tides continuously and regularly change the level of the water surface on time scales of minutes to days, with ranges from centimeters to meters. Wind and storm tides change the water surface level on a very irregular basis—ranging in time from hours to days and from seasonal to decadal storm patterns—with wave heights ranging up to 10 meters or more. As the tides change, so does the location of the two-dimensional shoreline. This results in development of a broad three-dimensional shore zone composed of many different shorelines.

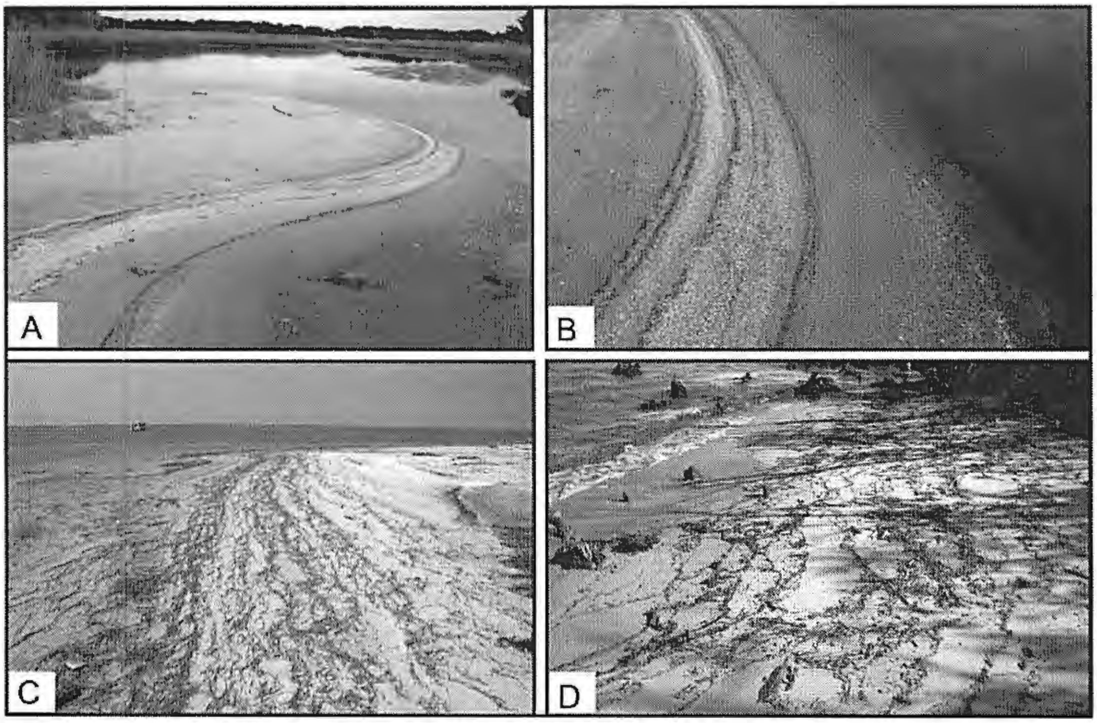


**Figure 1-18. The shore zone consists of a series of many shorelines that move up and down continuously on short-term time scales. Each debris line in this photo series represents an individual shoreline that was formed by wave energy as the falling water level stopped for brief periods at each level. Panels A and B. The land surface has a relatively steep slope so the shore zone tends to be narrow. Panel B is a close-up of a portion of the shore zone of Panel A and shows the closely spaced shorelines that comprise a narrow shore zone. Panels C and D. Two examples of land surfaces that have lower slopes and consequently the multiple shorelines are further apart and produce a broader shore zone. All photographs are by S.Riggs.**

Development of a Beach. A shoreline or shore zone does not constitute a beach. If sediments are available, the shoreline in any size water body will be characterized by a beach. Beaches form at many different scales—ranging from those that form in small rain puddles, to various sizes of lakes and estuaries, to the very large-scale oceans. The main difference between these various systems is the amount of energy available to build the associated beach. Ultimately, the production of any beach is dependent upon four basic factors:

1. Presence of a water body,
2. A land surface that contains the water body,
3. Wave energy impacting the water, and
4. Availability of sediments.

The specific or regional character of any given beach is directly dependent upon its geologic inheritance, which more specifically includes:

1. Size, shape, and depth of the water body,
2. Nature and intensity of the physical forces within the water body,
3. Geometry and composition of the underlying geologic framework, and
4. Latitude/longitude and associated climatic conditions.

The resulting beach can be a saltwater ocean (Cover Figure), a brackish water sound (Figure 1-18), a freshwater lake, or even a rain puddle in a field or on the street. The water body must be bound by a land surface that contains the water and rises above the water along the edge of the water body. This is the container that holds the water. A shoreline occurs wherever the water surface intersects the land container. The shoreline is a two-dimensional line of intersection between the water and land surfaces. However, the wall of the container can occur at any slope—ranging from a vertical wall that drops into deep water at the shoreline (Figure 1-19A) to a very low slope that forms a broad shallow water ramp that extends far offshore. The shape of the container along the shoreline will ultimately dictate the type of shoreline that can form. A vertical rock wall will produce a rock-bound shoreline (Figure 1-19A) because there is no place upon which to build a beach. Sediments derived from the erosion of the rock wall will sink into deep water.

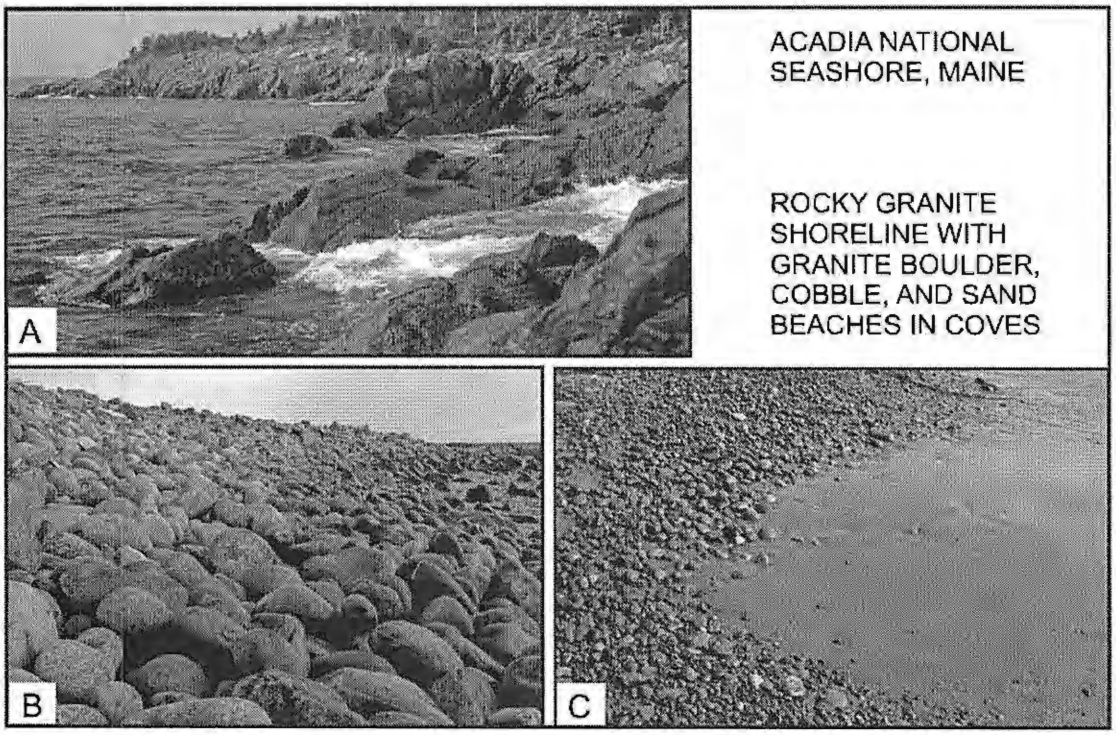
Waves. The friction of wind blowing across any body of water creates waves that can range from 1 centimeter high ripples on a puddle, to 1 meter high waves on a small lake, to 10 meter or higher waves on the ocean. The size of the wave form is dependent upon four factors:

1. Depth of the water,
2. Velocity of the wind,
3. Duration of the wind, and
4. The water distance over which the wind blows (fetch).

As any of the above factors increases, the size of waves will increase. Waves transport energy that must either be translated into other forms of energy (for example heat energy) or must do work. As long as the wind continues to blow, waves formed in deep, open water move unimpeded through the water. But as the waves move into shallow water, they begin to change form and perform an incredible amount of work. The work done by waves as they intersect the shoreline is to erode, transport, and deposit sediments in the form of beaches.

In addition, the beach is an environment of highly variable physical energy condition—ranging from dead calm water to the extreme wave and storm-tide conditions associated with major storms (Cover Figure). As a result, the beach is like a great energy transfer station where physical energy of waves, tides, and currents in the water is transferred to the land through work processes that cause the erosion, transport, and deposition of sediments associated with the land surface.

Sediment. Another factor necessary to form a beach is the presence of sediment available for transport by wave energy. If a shoreline occurs on a vertical rock wall that drops into deep water, the full force of the wave energy will be expended directly on the rock wall. A rock wall consisting of dense, hard, nonfractured rock (i.e., granite, basalt, limestone, etc.), will reflect wave energy directly off the wall with little or no erosion. At this stage you will have only a rocky shoreline with no beach because there is neither a shallow slope upon which a beach could accumulate nor sediments available to build a beach (Figure 1-19A). However, on a shoreline occurring where the vertical wall consists of softer sediments (e.g., sand and gravel, mudstone, peat) wave energy will erode a wave-cut scarp and wave-cut platform into the wall through time. Eventually, the ongoing erosion of the softer sediment wall forms a shallow platform that will eventually become available for the accumulation of eroded sediments (Figures 1-19B and 1-19C). The resulting high-energy strandplain beaches are often small and occur as ephemeral pocket beaches between more resistant rocky headlands (Figure 1-19B). These are the most common beaches that occur around the world (e.g. western U.S. Pacific coast, northeastern U.S. and Canadian Maritime Atlantic coast).



**<u>Figure 1-19</u>. <u>Panel A</u>. The shoreline on a steep granite rock wall that drops into deep water produces a rocky shoreline with no beach because there is neither a shallow slope upon which a beach could accumulate nor sediments available to build a beach. <u>Panels B and C</u>. Adjacent to the rocky headlands, erosion of softer material produces coves with shallow eroded terraces or platforms that accumulate the eroded sediment and form strandplain beaches. The resulting strandplain beaches occur as pocket beaches between more resistant rocky headlands and are composed of the material eroded from the rocky shoreline. In Panel B the beach consists of rounded granite boulders, and in Panel C the beach is composed of granite cobbles and sand. Photographs are by S. Riggs.**

As the slope of land around the edge of the basin decreases or becomes less steep, several things happen. First, as waves travel across low-sloping ramps, much wave energy is absorbed as the waves drag along the shallow bottom. Thus, relatively small waves dominate these shorelines. Second, the low-sloped ramp provides a platform upon which the resulting wave energy can build and maintain a sediment beach, if there is an adequate sediment supply available (e.g., southeastern U.S. Atlantic coast, U.S. Gulf coast).

<u>Beach Composition.</u> The beach will be composed of whatever sediments are locally available. For example, the beaches in Acadia National Park consist of large pink granite boulders, cobbles, and sand (Figures 1-19B and C). These coarse sediment beaches form as the wave-cut platform and wave-cut scarp erode into massive pink granite bedrock that forms the geologic framework of the region (Figure 1-19A). The black sand beaches of Hawaii are derived from the volcanic basaltic lava

flows that form the eroding rock scarps around the island's volcanoes. Waikiki Beach is an example of a white sand beach composed of carbonate sands derived from coral reefs. At Waikiki and other similar sites in Hawaii, sediments have covered the basalt scarps and filled the deep embayments, providing a suitable habitat for the establishment of coral reefs.

Geologic Framework. The underlying geology (i.e., the origin, geologic history, and rock types) determines the local variations in basin geometry and composition. Beaches forming along the resulting coastal segment will form along a continuum of coastal types. At one end of the continuum are strandplain beaches in which the sediment beach is perched on a wave-cut platform and in front of a wave-cut scarp. At the other end of the continuum are the shorelines that occur on an extremely low-sloped ramp where a barrier island and associated estuarine system can develop. The geomorphology of this flooding surface will dictate the size and type of back-barrier estuarine systems. The sediment availability along any given coastal segment will determine whether the barrier island system will be a sediment-starved, overwash/inlet dominated barrier island or a sediment-rich, complex barrier island system.

## Student Learning Cycle

### Engage:

Ask these questions to begin discussion:

1. If a shoreline is defined as any intersection of water and land, where might you find shorelines in your school yard, community, or county?
2. If you set up a time-lapse camera to photograph the shoreline of a puddle, pond, lake, or river, what would happen to the shoreline over a period of hours, days, months, or seasons?

### Explore:

Materials Needed:
Graph paper
Rulers

Individual or group assignment: Students may need help getting started with this assignment.

1. On a piece of graph paper draw profiles of a series of shorelines intersecting with the ocean at the following angles: $90^0$, $30^0$, $5^0$. (See Figure 1-17 as an example.)
2. As the slope of the land gets smaller what happens to the resulting shore zone or beach in response to fluctuations in water level as it rises and falls in response to storm rainfall and storm tides? (Reminder: the shore zone is the area between the different water levels—a zone through which the shoreline moves that is called the beach.)
3. Make a scale drawing on your graph paper to show the effect of a 3-foot sea-level rise on the different slopes you constructed in number 1. Label the horizontal and vertical axes. Describe the effect of different land slopes upon the resulting beach width.
4. Wave energy is a major factor in the formation of beaches along a shoreline. Using your textbook or other resource book, draw a diagram of a wave and label the parts.
5. Trace the transfer of energy from the sun to waves and identify the types of energy at each point.

### Explain:

There is a great deal of information from which you can choose to connect to the students' exploration regarding shorelines, beaches, and waves.

## Extend:

Using library or Internet resources, collect pictures that demonstrate a variety of different types of beaches (e.g., California, Mississippi River Delta, Florida Keys, Maine, Hawaii, North Carolina, etc.). Choose one of the beaches, learn about its geology, and propose ideas about how the beach was formed.

Find the meaning of the term "geomorphology." What is its relationship to topography? Discuss the geomorphology of the flooded surfaces in the beach pictures you collected.

## Evaluate:

Choose some of the pictures collected by students in the extension activity. For each one, ask students these questions:

1. Where is the shoreline?
2. Where is the shore zone?
3. Estimate the angle of the intersection between water and land.
4. How does the angle relate to the width of the shore zone?
5. Where does the beach material come from in the photos?

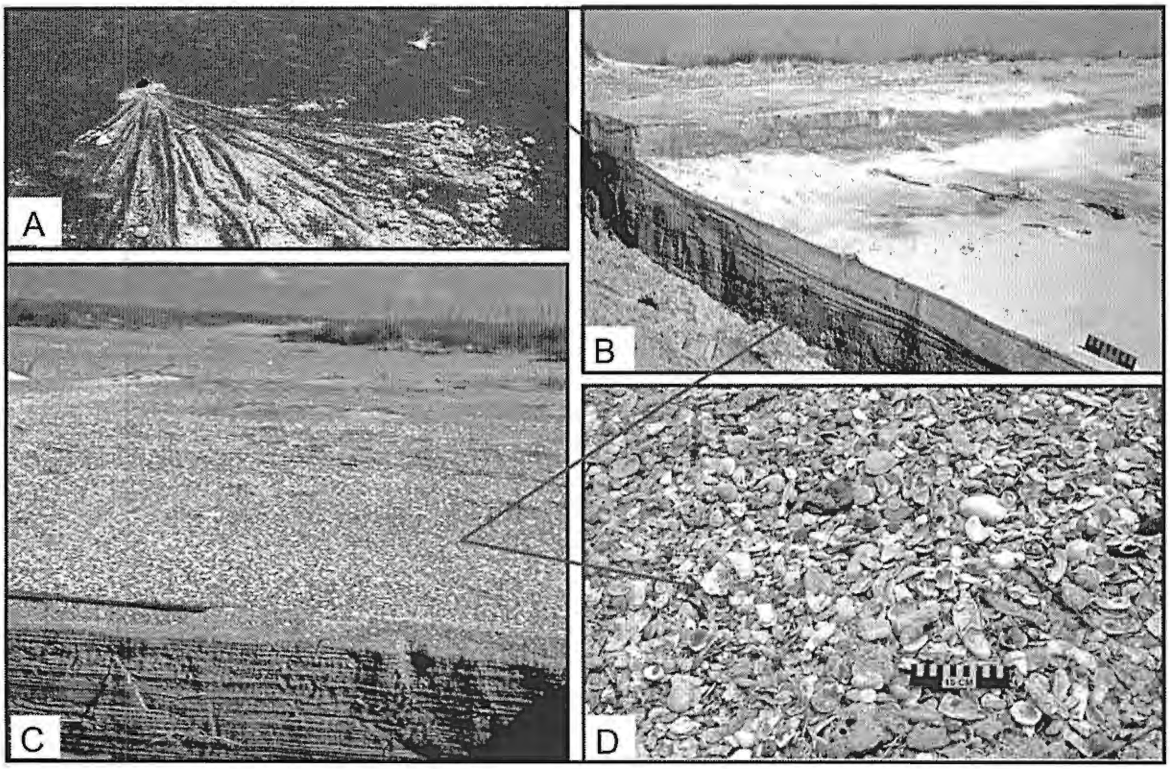
## Lesson Twelve: Ocean Beaches

### Teacher Background Information:

The sand beaches on North Carolina's barrier islands are composed mainly of quartz sand, with varying amounts of abraded shell material and local areas with minor concentrations of black heavy mineral sand and river gravel (Figure 1-20). The quartz sand and associated black sand and river gravel were derived from eons of erosion in the Piedmont and Appalachian provinces. Subsequently through time, rivers along the Atlantic margin transported these eroded sediments into the coastal region and deposited them as riverine channel fills and delta deposits. With fluctuating sea level, these old riverine deposits have been eroded and reworked many times into various coastal deposits and finally into the present barrier islands. The shell component consists only partly of modern shells of organisms presently living within the surf zone and associated continental shelf environments. Most of the shells on the North Carolina beaches are fossils that range in age from thousands to hundreds of thousands of years old.

The most abundant shells on many beaches are the gray to black-stained oysters (*Ostrea virginica*) (Figure 1-20D), which live only in the estuaries behind the barriers. They lived, died, and were deposited in the mud and peat sediments that form in the back-barrier marshes. In response to ongoing sea-level rise, the barrier islands migrate upward and landward over the back-barrier marsh deposits. With time these marsh deposits, along with the included oysters, crop out in the surf zone, erode during storms, and are supplied back to the beach as blocks of peat and fossil oysters. This represents an important source of "new" sediment that continues to feed the beach through time. The oysters generally date from a few hundred to several thousands of years in age.

The orange iron-stained shells on the beach (Figure 1-20D) often range from tens to hundreds of thousands of years old. Many of these shells were on the surface of the continental shelf during the last glacial episode (20,000 to 14,000 years ago). During this time period, the North Carolina shoreline was below the outer continental shelf, about 425 feet below present sea level and between 15 to 60 miles offshore of the modern shoreline. During this period, the continental shelf was part of the Coastal Plain, and these shells occurred within the soil profile that developed on the exposed surface of the continental shelf and became iron stained by the soil that developed on the sediment surface.



<u>Figure 1-20.</u> **Sand beaches on North Carolina's barrier islands are composed mainly of quartz sand with varying amounts of abraded shell material and local areas with concentrations of black heavy mineral sand and river gravel.** <u>Panel A</u>. **White quartz sand is covered by a thin layer of black heavy mineral sand. The underlying white sand is exposed on the surface by a burrowing ghost crab.** <u>Panels B and C</u>. **Photographs of two beaches that consist of alternating beds of white quartz sand and shell gravel as exposed in the trenches dug across the beaches. In Panel B the white sand is on the surface. In Panel C the shell gravel is on the surface. These alternating beds are deposited by changing water levels in response to either astronomical tidal or storm tide cycles.** <u>Panel D</u>. **A close up photograph shows the abundant orange and gray stained shell gravel that commonly occurs on the ocean beaches. Photographs are by S. Riggs.**

Among the largest shells found on the beach are the quahogs or cherrystone clams (*Mercenaria mercenaria)*. Some of these shells that contain the beautiful purple coloration on the inside of the clam shell are modern in age. These clams live on the adjacent sand flats within inlet ebb and flood-tide deltas. However, most of these shells range from bleached white to dark amber brown and are often tens to hundreds of thousands of years old. These older *Mercenaria* shells are being eroded out of older layers formed during the Pleistocene and cropping out on the shore face and inner continental shelf during storms. Notice that many of these shells, once they are on the beach, eventually break down in the 'ball mill' of the high-energy surf zone into smaller sized particles—severely abraded gravels and much finer grained, flat and rounded shell sand grains. It is this fine gravel and coarse sand shell material that gives the beaches their variable orange colorations as you look across the beach. Most medium and fine-grained sand beaches are gray colored due to the dominance of quartz sand with a total lack of shell particles among this grain size fraction.

The black heavy mineral sands (Figure 1-20A) are composed of various types of very hard and chemically stable heavy minerals. The dominant black minerals (illmenite and magnetite) include lesser abundant red minerals (garnet and rutile) and the rare pale green and blue minerals (tourmaline, zircon, apatite, etc.). Because these minerals are much heavier and denser than quartz and calcite, they tend to be fine to very fine sand size grains and occur with coarser grained fractions of quartz and calcite sand. Consequently, the heavy mineral sands tend to occur in the upper portions of the storm beach and are particularly concentrated around inlets and capes.

## Student Learning Cycle

**Engage:**

Show a slide of Figure 1-20. Explain the different kinds of materials found on these beaches. Ask students about beaches they might have visited. What kinds of beach material were there? Has anybody been to a beach that has recently had beach nourishment? What kinds of materials do you find there that is different from the original beach material?

**Explore:**

Materials Needed:

For each student: A copy of the information about beach materials from the teacher background information and a copy of the chart (below) calling for information about beach materials

| Type | Source | Appearance | Location on the beach |
|---|---|---|---|
| Quartz sand | | | |
| Shell materials (oysters) | | | |
| Shell materials (*Mercenaria*) | | | |
| Heavy Minerals | | | |
| River gravels | | | |

Have students individually complete the chart with data found in the reading.

**Explain:**

Use student results as a basis to reinforce important concepts in the teacher background information.

**Extend:**

Give each group a sample of beach material from one of North Carolina's ocean beaches. Have the students sort the materials, describe the different kinds of materials and speculate as to the source of the material and how they might have gotten to the beach (with reasons). You may also provide beach materials from rivers or lakes in your area. Sort and describe materials and compare to ocean beach material.

**Evaluate:**

Describe different kinds of beach materials found on the ocean beaches of the Outer Banks. Explain how they got to that location and ended up as sand-sized particles.

## Lesson Thirteen: Estuarine Shorelines Behind Simple Overwash Barrier Islands

### Teacher Background Information:

Figures 1-13, 1-14, and 1-16 illustrate the difference between simple overwash barrier islands (narrow and low) and complex barrier islands (wide and high). The North Carolina Outer Banks consist of both types.

Back-barrier shorelines associated with simple overwash-dominated barrier islands such as major portions of Pea Island, Ocracoke Island, and the Avon-Buxton site are greatly affected by events occurring on the ocean side. Because these barrier segments tend to be sediment poor, they are extremely dynamic with severe erosion on the ocean side (between 5 to 12 feet/year based upon the N.C. Division of Coastal Management's long-term average annual erosion rates). The consequence is extensive formation of both overwash fans and inlets in response to storm surge events (Figures 1-21 and 1-15). Sediments eroded from the ocean side are supplied through overwash and inlet processes to the continuous building of the back-barrier portion of the island at the expense of the ocean side. These deposits form extensive shallow-water sand platforms in the back-barrier estuaries that are quickly colonized by salt marsh and aquatic grasses. The growth of aquatic, inter-tidal, and subaerial vegetation stabilizes the sand platforms and continues to trap more sand with time. The heavy growth of vegetation helps to stabilize the newly developed estuarine shoreline.

When a storm directly impacts a narrow and weak portion of the simple overwash barrier islands, a new inlet will frequently form. Currents associated with the storm surge that opens the inlet, as well as subsequent tidal currents that keep an inlet open, build an extensive system of shallow sand shoals in the estuary behind the barrier known as the flood-tide delta. As long as the inlet remains open, the currents build these shallow-water sand shoals. However, as soon as the inlet closes down, either naturally or due to human intervention, the shallow sand shoals become heavily vegetated with aquatic and inter-tidal growth that stabilizes the sand platforms.

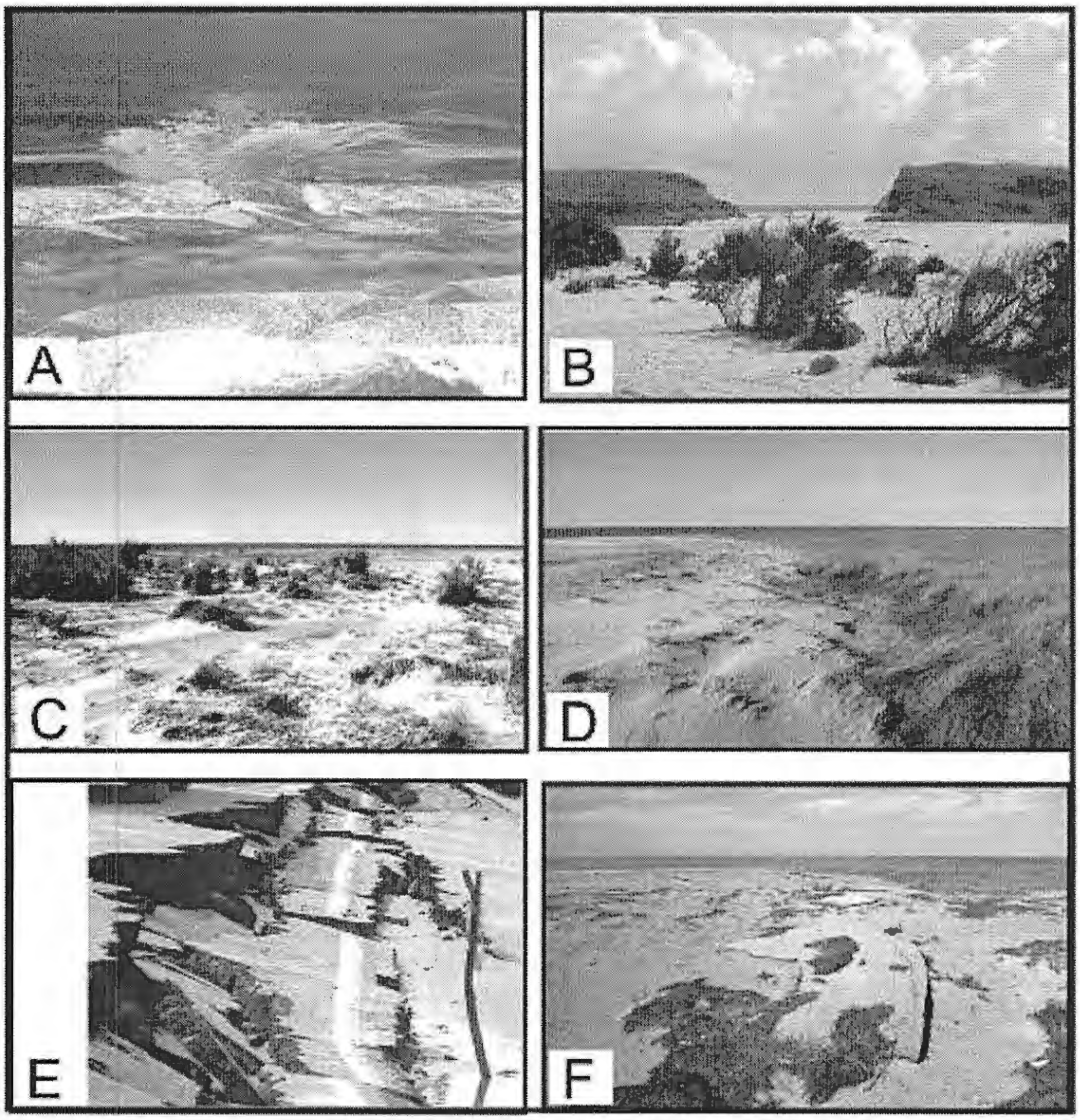


**Figure 1-21.** Post-Hurricane Isabel photos of NE portion of Ocracoke Island that destroyed about 6 miles of N.C. Hwy. 12 and nourished the back-barrier marsh platforms. Panel A. Oblique aerial photo shows a breach in the barrier-dune ridge and the resulting overwash fan that buried N.C. Hwy. 12 and extended into the marsh. Panel B. Ground photo of a similar situation shown in Panel A. Notice the breach in the barrier-dune ridge through which the overwash fan was transported. Panel C. Photo shows an overwash fan that has buried the shrub-scrub zone and extends out into the back-barrier marsh. Panel D. Photo shows the end of an overwash fan that has buried and built up the platform marsh. Panel E. Photo shows a destroyed segment of N.C. Hwy. 12 that resulted from shoreline recession, placing the highway in the storm beach. Panel F. Overwash fan in the back-barrier marsh consists of beach sand, along with large pieces of N.C. Hwy. 12 that were transported along with sand into the marsh and out into the sound. Photographs A and B are by Cape Hatteras National Seashore personnel. Photographs C through F are by S. Riggs.

Marsh shorelines behind simple overwash barriers occur on distinct overwash fans and are composed of relatively thin (less than 3 ft) mixed peaty sand to sandy peat sediment. Because overwash processes renourish these fans over time, the associated marshes and their shorelines tend to be gently ramped and are fairly stable and persistent through time. However, with the human modification of the island through construction and maintenance of barrier-dune ridges to protect N.C. Hwy. 12, overwash processes have been minimized and many marsh platforms have begun to erode around the perimeter.

Overwash and inlet processes are crucial for the long-term maintenance of the islands in two ways (Figures 1-21 and 1-15). First, both overwash and inlets add width to the back or estuarine side of the island. Second, overwash processes carry sand over the top of the island and build elevation on the very low portions along the back side of the barrier. These processes are crucial for the overall maintenance of island width and elevation because the islands are migrating upward and landward in response to the ongoing processes of sea-level rise (Figure 1-6). Without either of these processes, the ocean side will continue to severely erode, resulting in the island becoming both narrower and lower until it ultimately drowns with the limited sand being spread out into a broad shoal system.

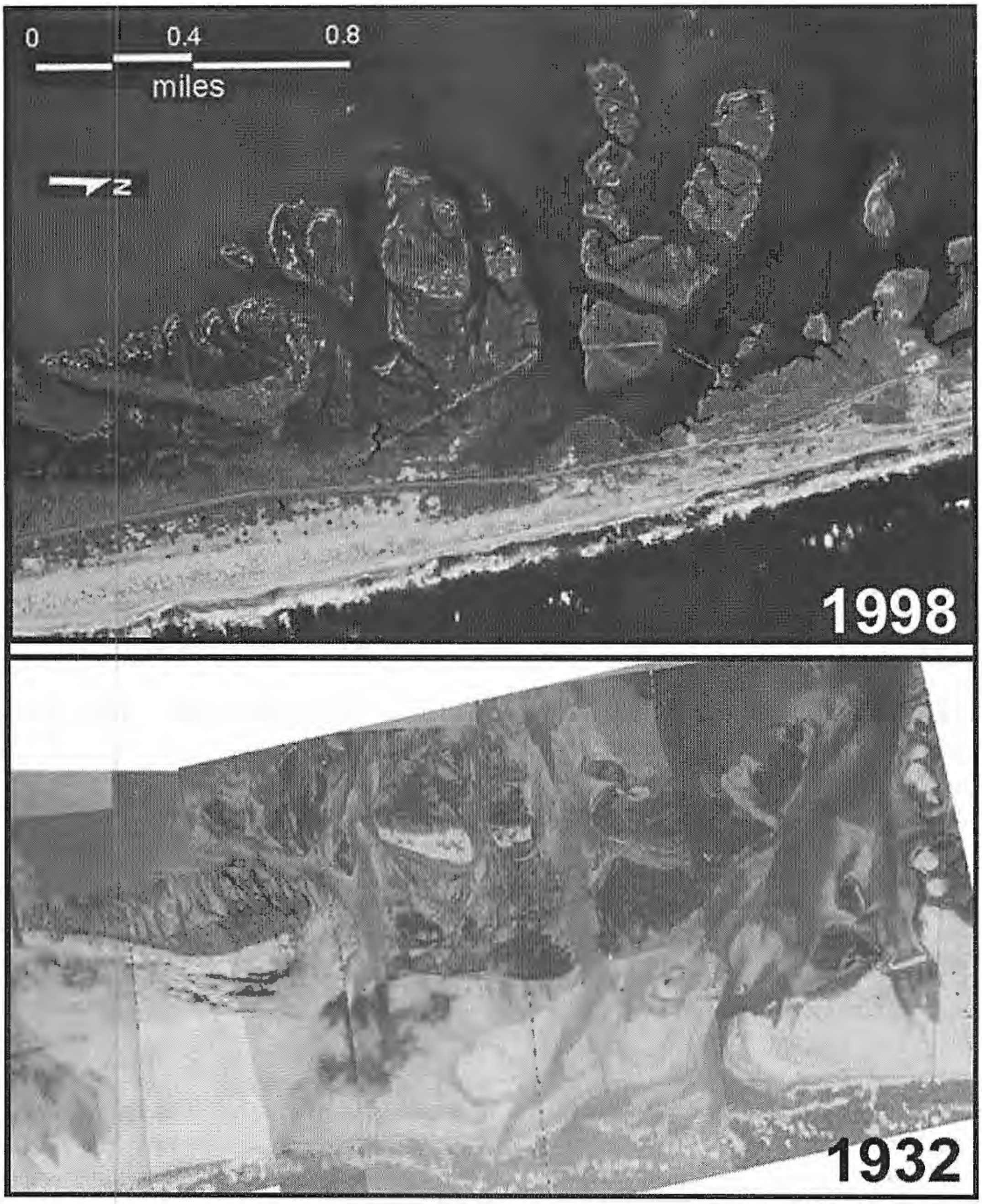


**Figure 1-22. Two aerial photographs of New Inlet on Pea Island show the open and active inlet in 1932 and the closed inlet in 1998 long after it closed naturally in 1945. Panel 1932. A black and white aerial photograph that shows the extensive sand shoals that form an ebb-tide delta on ocean side and a flood-tide delta in the sound behind the barrier island with multiple inlet channels. Panel 1998. A color aerial photograph shows the subsequent loss of the ebb-tide delta and the evolution of flood-tide delta sand shoals to estuarine salt marsh. Notice the location of N.C. Hwy. 12 along the front side of the barrier and the remnants of the historic New Inlet bridge across the flood-tide delta salt marshes. Figure is modified from Riggs and Ames.**

However, both of these natural and crucial processes are in serious conflict with human development. Neither process is friendly to houses, businesses, or roads that expect a permanent and non-mobile barrier island. Figures 1-14, 1-21, and 1-28 show the extensive overwash fans that resulted from Hurricane Isabel. The storm surge eroded out sections of the barrier dune ridge, buried or tore up segments of N.C. Hwy. 12, and opened a major inlet near Hatteras Village (Figure 1-5). Also, these important processes built critical elevation and width essential for the long-term maintenance and health of the barrier island. The critical question is: How can humans and their economic developments cope with a dynamic barrier island that is gradually rolling over itself as sea level rises?

## Student Learning Cycle

### Engage:

Show a slide of Figure 1-5. Ask students to speculate as to what would have happened to the estuarine shoreline behind the inlet if the inlet had been left open after Hurricane Isabel? Show a slide of Figure 1-22. Explain that the 1932 photo shows the inlet that was formed across Pea Island by a storm. The 1998 photo shows the same area long after the inlet closed naturally in 1945. What happened to the sand shoals that formed a flood-tide delta behind the island?

### Explore:

Have students discuss these questions in their groups and then conduct a whole class discussion:

(1) In what ways are overwash and inlet processes crucial for the long-term maintenance of the simple overwash barrier islands?
(2) When does each of these processes happen and how do they effect the back-barrier estuarine shoreline?What happens to an inlet's flood-tide delta when the inlet is closed by either natural or human processes?
(3) Why are these two natural and crucial processes in serious conflict with human development?
(4) Since neither overwash nor inlet processes are friendly to houses, businesses, or roads, what is the usual human response? How does this response affect each of the natural processes?

### Explain:

Use the teacher background information to connect new details about the development of estuarine shorelines behind simple overwash barrier islands.

### Extend:

Look at a slide of Figure 1-14, a segment of the Outer Banks just north of the village of Rodanthe. Note in the upper aerial photo the overwash of beach sand from the ocean side to the sound side caused by Hurricane Isabel in 1998. What happened to N.C. Hwy. 12? What problem did this present for inhabitants of the island? N.C. Department of Transportation pushed sand off the highway back to the ocean side of the island. What would have happened to this section of the island if they had left it as it was after the hurricane?

### Evaluate:

Write a paragraph explaining how the processes of overwash and inlet formation contribute to the maintenance of a simple overwash barrier island.

## Lesson Fourteen: Estuarine Shorelines Behind Complex Barrier Islands

Teacher Background Information:

Complex barrier islands (Figures 1-13B and 1-16), such as Kitty Hawk Woods, Nags Head Woods, and Buxton Woods, represent sediment-rich island segments. These high and wide barrier islands contain large volumes of sand in the form of beach ridges and back-barrier dune fields that do not allow inlets to form or overwash events to flow over the island. Rather, overwash is restricted to a narrow zone along the front side of the barrier. Thus, the back-barrier estuarine system is largely unaffected by oceanic processes and operates in a fashion similar to other mainland estuarine shorelines. The back-barrier estuarine shorelines are either eroding sediment-banks or eroding marsh platforms. The Nags Head Woods-Nags Head Cove Site illustrates both eroding sediment-banks and eroding marsh platforms.

Marsh Platform Shorelines. Because the Northern Coastal province of North Carolina is characterized by few inlets through the barriers (Figure 1-11), fluctuating water levels are generally caused by irregular wind tides, except when adjacent to the inlets where astronomical tides are also important. Thus, marshes are generally wave dominated with irregular storm-tide flooding and water that ranges from middle- to low-brackish. This situation determines the following basic characteristics of the northern marshes:

1. They tend to occur as vast and spectacular wetland habitats that form as broad, flat platforms with few tidal creeks. (Tidal creeks typically occur around major overwash plains or inlets.)
2. The marshes are dominated by black needle rush, with narrow outer rims of salt meadow hay or salt marsh cordgrass.
3. The outer shoreline in most areas exposed to a significant fetch is in a destructive or erosional phase characterized by an undercut vertical erosional scarp.
4. Upslope, the marsh grades into a transition zone of small shrubs composed of wax myrtle, marsh elder, and silverling. Notice in Figure 1-23 that trunks of dead trees often remain standing, a sign that the salt marsh is moving inland, killing species of plants that are intolerant to salt water and rising water level.
5. The transition zone grades into the adjacent upland that may be composed of pines and hardwoods (Figure 1-23)
6. Freshwater marshes occur within the island interior and typically host cattails, bullrushes, and reeds.

**Figure 1-23. Photograph of a typical shoreline transition zone—from the marsh grasses at the edge of the shoreline through shrub-scrub such as wax myrtle and pond pine—to the upland pines and hardwood trees in the background. The tree stumps in the water and standing dead upland pines behind the shoreline are a direct response to rising sea level, which drowns the upland trees as the transition zone and marsh vegetation migrate upward and landward. Photograph is by S. Riggs.**

Marsh shorelines behind complex barrier islands are characterized by the accumulation of thick beds of peat deposited in response to rising sea level. Peat is formed by the accumulation of organic materials (from the marsh grasses) over a long period of time. Most marshes that constitute the back-barrier shoreline are highly irregular (Figure 1-24A) and eroding marsh platforms that display steeply scarped perimeters and vertically drop off into several feet of water. The upper portion of the marsh peat is bound by a dense root mass from the living marsh plants. Below this root mass, the peat is decomposed, very soft, and highly erodible. A low tide places water level below the root mass of the modern marsh grasses, which forms an extremely tough upper 6-12 inch layer. Thus, the wave energy is expended against the underlying layer of soft decomposing organic matter, which easily erodes to produce a major undercut surface (Figure 1-24B). With time, the overhanging root-bound mass will break off and fall to the estuarine floor (Figure 1-24A) where it is slowly broken down. This is the main mechanism of erosion along the marsh shorelines. If the outer marsh perimeter is exposed to large stretches of open water with high wave energy, the peat sediment is actively eroded, producing vertical and undercut scarps that drop abruptly into relatively deeper water (greater than 2 feet).

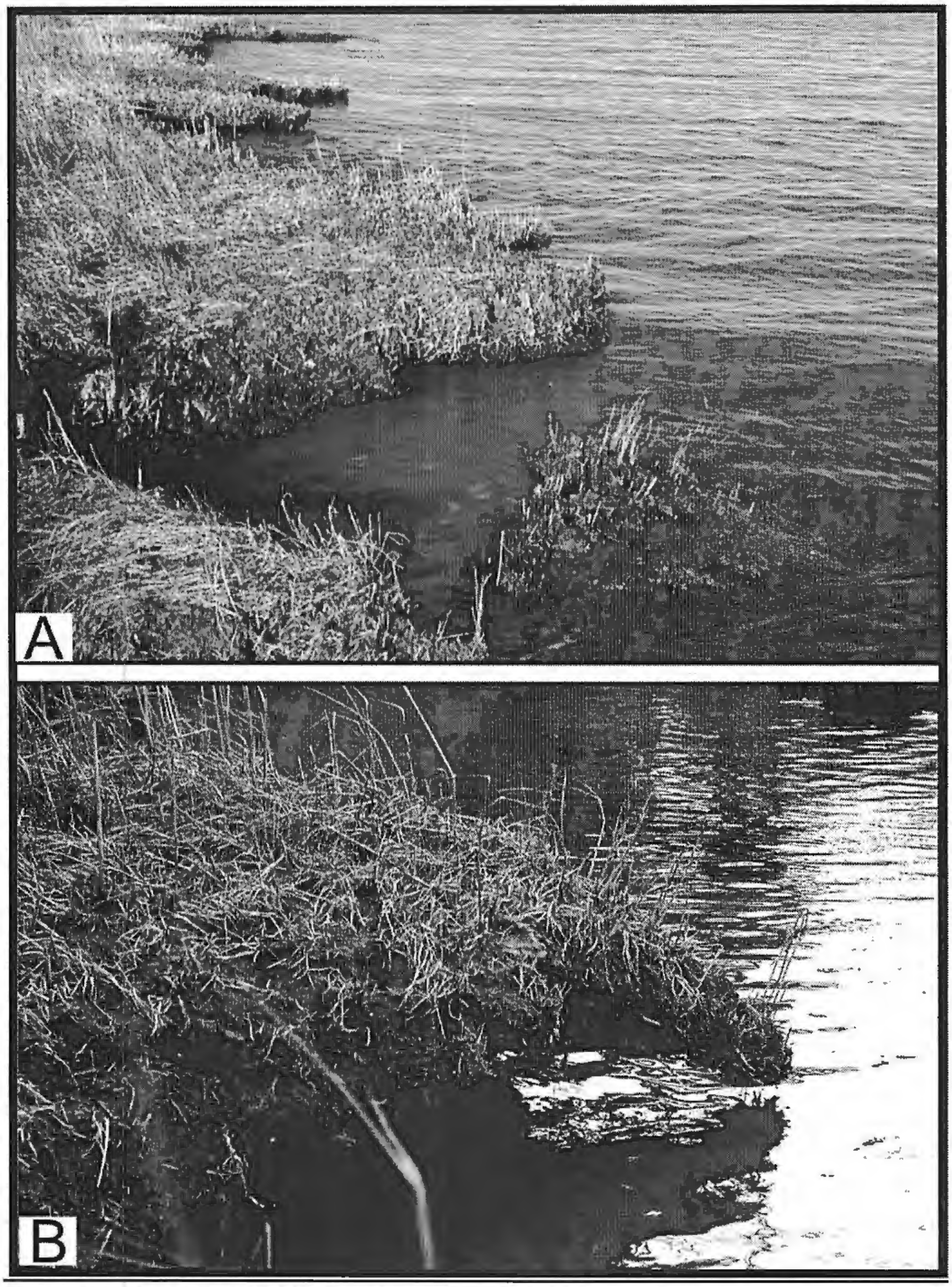


Figure 1-24. Panel A. A highly irregular and eroding marsh platform shoreline occurs at Wades Point along the Pamlico River, Beaufort County. Nags Head Woods has similar steeply scarped and undercut platform marshes. The upper peat is bound by a dense root mass of modern marsh plants. Below this root mass, the peat is decomposed, very soft, and highly erodible. As the platform is undercut, large blocks of the upper bound peat break off as can be seen in the lower right hand corner. Figure 8-4-1 Panel F, p. 124 in Riggs and Ames (2003). Panel B. Wave action during low tide levels erodes the soft peat layer underlying the tough root-bound modern marsh surface to produce this severely undercut peat block. During higher water levels, wave energy causes the root-bound overhang to break off—this is the mechanism for eroding marsh shorelines. Figure 8-2-16, Panel D, p. 96 in Riggs and Ames (2003).

Erosion of marsh peat shorelines is a major source of fine organic material that forms the organic-rich mud sediments within the estuarine system. The organic material helps to provide the nourishment that makes the estuary into "the nurseries of the ocean." Many fish species spend the first few years of their lives in the esturaries. Marshes provide critical habitat for many fish species and other vertebrates, as well as many invertebrate species.

As sea level rises, the landward side of these marshes migrates onto the adjacent upland areas (Figure 1-23). Thus, as the marshes are eroded on the estuarine side, they are generally expanding onto low-sloped uplands on the landward side. Rising sea level causes the ground-water level to rise, which stresses and finally drowns the lowermost zone of upland vegetation. The marsh accumulates peat sediment vertically, which allows the growth of grasses to keep up with sea level. This vertical growth in the marsh encroaches upon the upland, burying the old stumps and logs in the process. Landward expansion of the marsh continues until the upland slope becomes too steep or the upland is filled or hardened for development. Then marsh expansion is ended, and future rise in sea level will result in a net loss of marsh habitat.

Sediment-bank shorelines. Sediment-bank shorelines erode into older sand and clay sediment units and can range from low banks that are a foot high to bluffs that are more than 50 feet high. Because of differences in size and weight, waves wash away the very fine particles of mud, which may remain suspended in the water for quite some time. The heavier, larger sand grains are deposited at the shoreline to form a strandplain beach on top of a wave-cut platform (Figure 1-25) if the eroding sediment-bank contains adequate sand supplies. The sand that comprises the beach is derived primarily from the erosion of the wave-cut scarp on the adjacent sediment-bank. The beach forms along the water line and absorbs much of the day-to-day wave energy. The wave-cut scarp does not erode on a daily basis, but requires a high storm tide that causes the water level to overstep the sand beach and allows the wave energy to break directly on the sediment-bank. Bluffs and high sediment-banks are the least abundant types of shorelines and are in great demand for home-site development (Figure 1-26). Low sediment-banks are the most abundant type of sediment-bank shoreline in coastal North Carolina (Figure 1-27A).

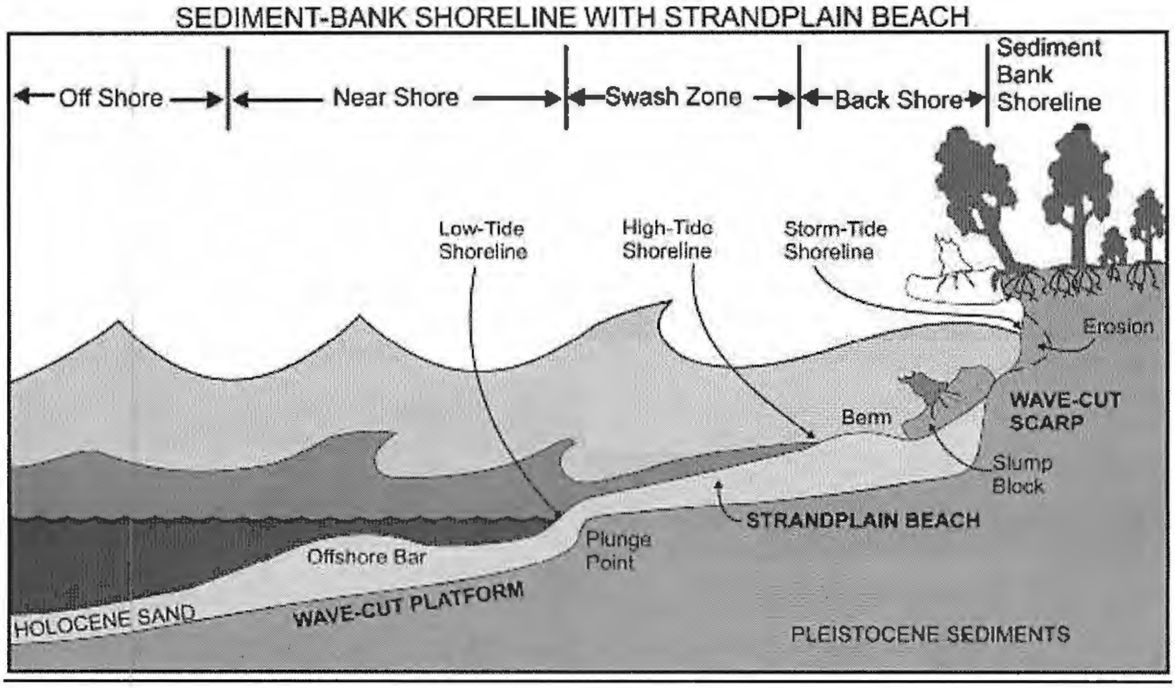


**Figure 1-25. Schematic model of a sediment-bank shoreline shows the following geomorphic features: 1) A wave-cut scarp and wave-cut platform have been eroded into older sediment units with a strandplain beach perched on the platform. 2) Different water levels and wave sizes that do the work of shoreline erosion, beach building, and beach maintenance. 3) The process of eroding and undercutting the bank top during high storm tides and subsequent slumping and reworking of slump blocks to produce the beach sediments. Figure 4-2-1, p.38 in Riggs and Ames (2003).**

Figure 1-26. A high sediment-bank shoreline in Nags Head Woods is being severely eroded by the wave energy along the eastern end of Albemarle Sound. However, erosion is not occurring during the low-energy conditions shown in this photo. Rather, bank erosion occurs during storm conditions when the water level oversteps the beach and directly intersects the sediment-bank. Notice the extensive strandplain beach that is derived from the erosion of the wave-cut scarp comprised of a sand sediment-bank. This Figure is on p. 24 in Riggs and Ames (2003).

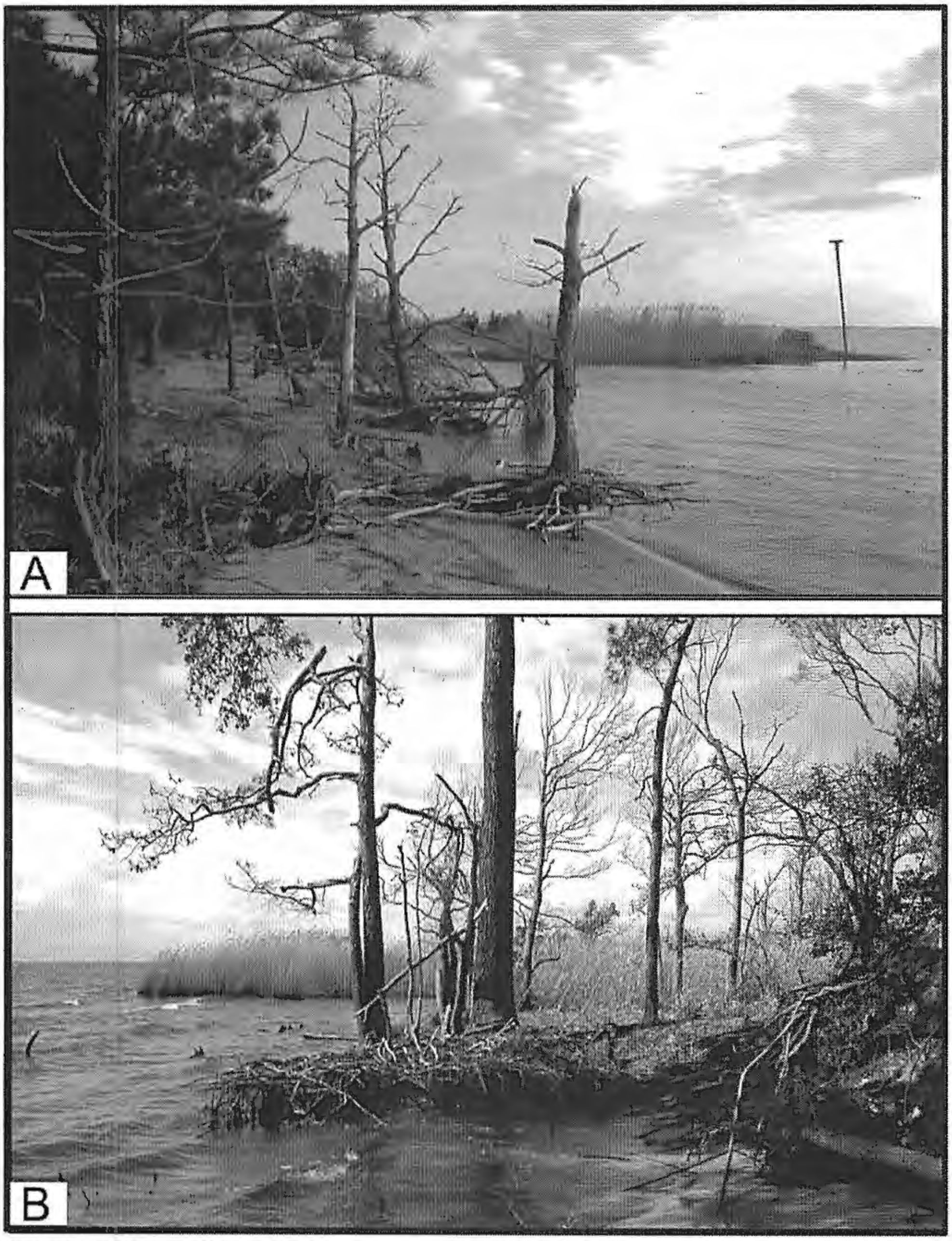


Figure 1-27. Low sediment-bank shorelines. Panel A. This photograph shows a shoreline along the estuary shoreline at Jockey's Ridge State Park. Much of the Nags Head Woods and Nags Head Cove shorelines are similar to this photograph. Notice how the sediment has been eroded from beneath the pine tree roots, leaving the dead trees standing in the water as the shoreline retreats. The minor sand that forms the strandplain beach is derived from the erosion of the low sediment-bank. Figure 8-2-11 Panel E, p. 91 in Riggs and Ames (2003). Panel B A low sediment-bank (in the foreground) and platform marsh (in the background) are actively eroding along the Nags Head Woods estuarine shoreline at the eastern end of Albemarle Sound. About two feet of sediment and topsoil have been removed by wave action, completely exposing the root structures of the slowly dying oak and pine trees. Notice the small sand strandplain beach in the lower right hand corner that is covered with wood debris forming natural breakwaters. Figure is on p. 68 in Riggs and Ames (2003).

Combination Shorelines. Shorelines often do not fit into one specific category (marsh or sediment-bank). Many shorelines are composed of both sediment-banks (high or low) with a zone of fringing marsh or swamp forest vegetation. These occur throughout the estuarine system and in all variations from marsh to mixed combinations of sediment-banks. Further complications occur when a given shoreline is modified by humans who either build structures, add new materials, or alter the landscape geometry.

Many strandplain beaches contain natural combinations that are beneficial to slowing the rate of shoreline recession. For example, sediment-bank shorelines with wide strandplain beaches develop fringing marshes in areas where the shoreline is somewhat protected. Vegetation along sediment-bank shorelines buffers wave energy and helps protect the adjacent shoreline in all but the largest storms. Marsh platform shorelines that have a source of sand can develop small strandplain beaches. Sand is often derived from offshore shallow-water sand bodies and transported onshore by storm tides. Sand can also be derived from the erosion of a particularly sandy unit underlying the shallow perimeter platform. The presence of a sand apron in front of a marsh shoreline will help absorb wave energy and protect the shoreline in all but the largest storms.

Low sediment-bank shorelines are frequently dominated by remnant forests of pine stumps in the water. Because pine trees have a deep tap root, sediment is frequently eroded out from around the stump as the shoreline recedes, leaving a ghostly tangle of stumps, logs, and roots in the shallows offshore (Figure 1-27). The resulting obstructions require boaters and swimmers to beware. However, removal of these remnants of the forests will result in the immediate increase in rates of shoreline recession.

## Student Learning Cycle

**Engage:**

Knowing the differences between simple overwash barrier islands and complex barrier islands, what do you think would be the difference in the impact of storms on the soundside of the islands (storms that come in from the ocean side)? Show students a slide of Figure 1-23. Inform them that this is a site on the soundside of Nags Head Woods. (Refer back to Figure 1-2 if necessary.) This is a complex barrier island. How would you describe what you see? How would you explain the dead trees?

**Explore:**

Materials:

1 copy per group of the following figures (including captions):

1-24, 1-25, 1-26

Answer the following questions using the figures you have been given:

1. If the high bank in Figure 1-26 is composed of a muddy sand, what happens to the sand and the mud during erosion?
2. What forces contribute to the work of shoreline erosion and beach building in Figure 1-25?
3. Compare mechanisms of erosion on shorelines shown in Figure 1-24 with those in Figure 1-26.
4. What is the source of sand that forms the beach in Figure 1-26? Is this an eroding shoreline? Explain.
5. Where do the tree trunks and limbs come from that you see on the beach in Figure 1-26?

**Explain:**

Summarize the different types of shorelines on the soundside of complex barrier islands. Be sure that students understand the forces that work on these shorelines and the different types of materials on which they work.

Provide students with information that enables them to answer these questions:

1. What is the difference in the effect of ocean-side processes (such as storms) on the soundside of a simple overwash barrier island and that of a complex barrier island?
2. Explain how each of the following forms:
    a. Transition zone
    b. Peat deposits in barrier island back-barrier marshes
    c. Undercut scarps in back-barrier platform marshes
3. How does a marsh grow vertically?

**Extend:**

Conduct a library/Internet search to find photos of plant species native to the salt marshes and submerged aquatic vegetation (SAV) along the barrier islands of North Carolina. Fill in the table below for each major species and determine what the relative salt tolerance is (fresh, low brackish, medium brackish, high brackish, or normal ocean salinity) and where it lives: submerged aquatic vegetation, low inter-tidal zone, high inter-tidal zone, or supra-tidal zone (storm tide).

| Species | Relative Salt Tolerance | Relative Water Level |
|---|---|---|
| Sea oats | | |
| Bull rushes | | |
| Wax myrtle | | |
| Marsh elder | | |
| Cattails | | |
| Marsh glasswort | | |
| Salt marsh cordgrass | | |
| Black needle rush | | |
| Salt meadow hay | | |
| Eel grass | | |

**Evaluate:**

Write a paragraph explaining the difference between a marsh shoreline and a sediment-bank shoreline (on the soundside of a complex barrier island).

## Lesson Fifteen: The Coastal Dilemma

### Teacher Background Information:

The effect of a storm in a shore zone depends upon the interaction of two major factors: 1) the type of shoreline (sand vs. rock, low-sloped ramp vs. vertical bluff, ocean vs. estuarine, etc.) and 2) the source, amount, and duration of energy expended. Storms represent the major new input of energy to a coastal system. Storm energy causes shore zones or beaches to change and evolve through time. Beaches absorb the physical energy occurring at the contact between sea and land.

Little happens to a beach on calm summer days. However, storms that transfer major amounts of energy can result in significant shoreline modification (Figure 1-28). The photos in Figure 1-28 show the result of tremendous energy exerted on everything in the path of Hurricane Isabel. Barrier-dune ridges, referred to in the photo captions, are not naturally occurring dunes but rather sand ridges that represent major human modification efforts to protect structures (houses and roads) from storm damage.

On a sandy beach, a storm tide will erode, transport, and redeposit not only sand but also structures built upon the sand—including houses and roads (Figure 1-28). As energy is expended by the storms, the character of the shore zone responds with dramatic changes, causing a dilemma for humans who wish to build homes and other structures on the barrier islands. Rates of change along the North Carolina shorelines are measured in time frames of days and years, in severe contrast to the expectations of permanence and economic values placed upon waterfront properties.

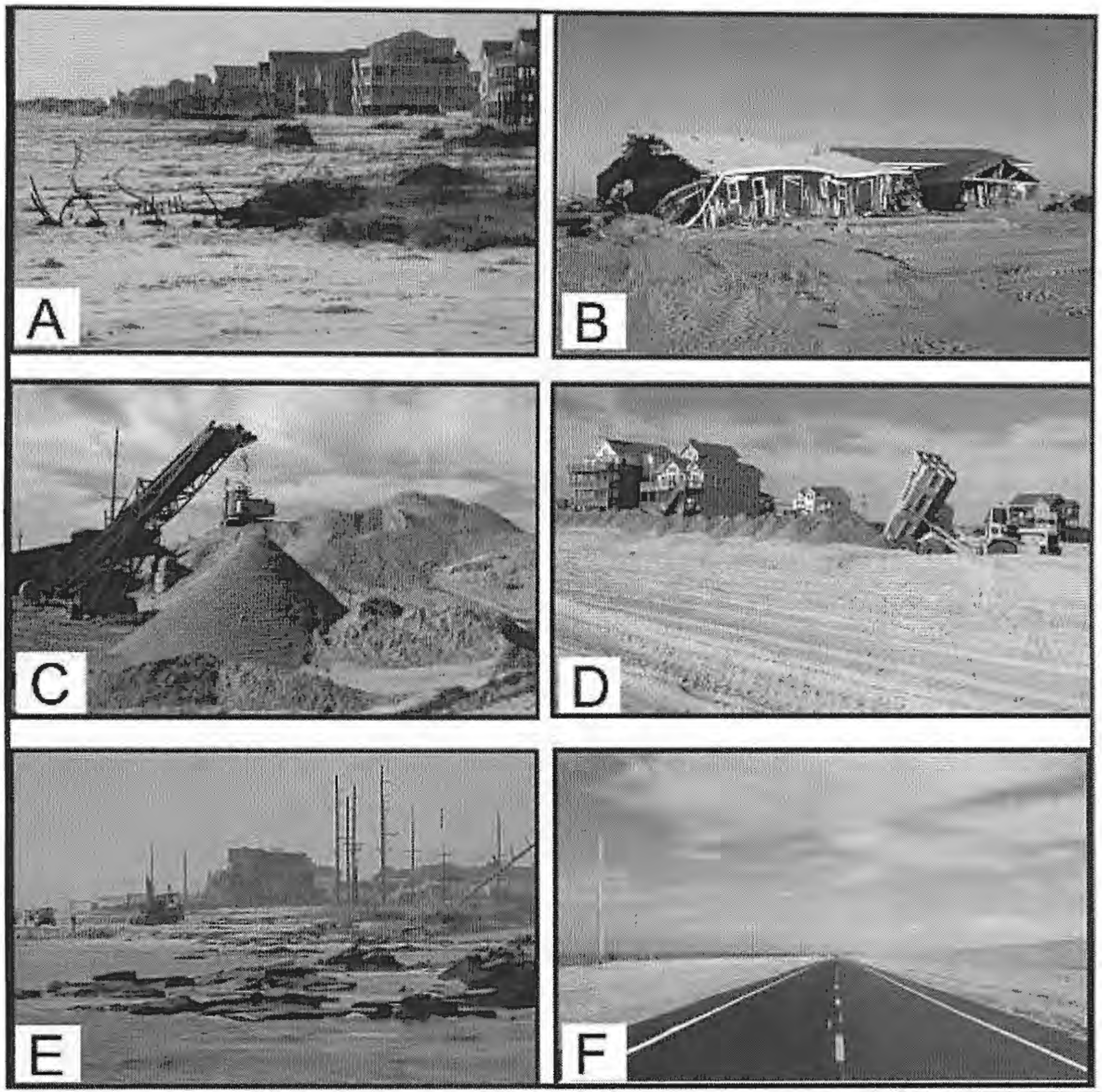


**Figure 1-28.** **Post-Hurricane Isabel (2003) photographs show the damage in Hatteras Village and the newly opened and quickly closed Isabel Inlet. Panel A. Storm surge and overwash destroyed large segments of the barrier-dune ridge. Panel B. This oceanfront motel was destroyed when the barrier-dune ridge was breached by the storm surge. Panel C. This expensive process cleans the debris from overwash sand for use in building the new barrier dune-ridge. Panel D. A new barrier-dune ridge is being constructed in front of the destroyed motels. Panel E. Remnants of N.C. Hwy. 12 pavement within Isabel Inlet. Panel F. This photograph depicts the infilled Isabel Inlet, reconstructed N.C. Hwy. 12, and rebuilt barrier-dune ridge. Photographs are by S.Riggs.**

Increasing numbers of storms greatly impact the barrier islands, sea level continues to rise (Figures 1-6 and 1-7), and the population living and building permanent structures on this dynamic coast increases sharply (Figure 1-4). All three processes are predicted to continue into the near future. According to a report by the Bureau of Census, U.S. Department of Commerce, Dare County experienced extremely high growth rates. Todd Miller, Executive Director of the N.C. Coastal Federation, stated in October 2001 (*http://www.nccoast.org/Newsroom/pressNortheast.html*).

> For the most part, the northeastern part of the coast has grown very slowly over the last ten years. A pair of inland counties (Washington and Bertie) actually lost population during the last decade, while Dare and Currituck were two of the top dozen fastest growing in the state. On top of the permanent population increase, seasonal housing in Dare County more than doubled, increasing by almost 7,000 buildings. Seasonal housing in Currituck County tripled, bringing even more seasonal visitors to a small strip of land.

Human development cannot be approached on a high-energy coastal shoreline the same way that development in Raleigh or Charlotte would take place. For long-term success for both society and the coastal ecosystem, decision makers must face the inevitability of change and utilize the valuable coastal resources in ways that are in harmony with the energy and processes of the natural system. Figure 1-29 shows the long-term change (over 132 years) in the ocean shoreline of Ocracoke Island.

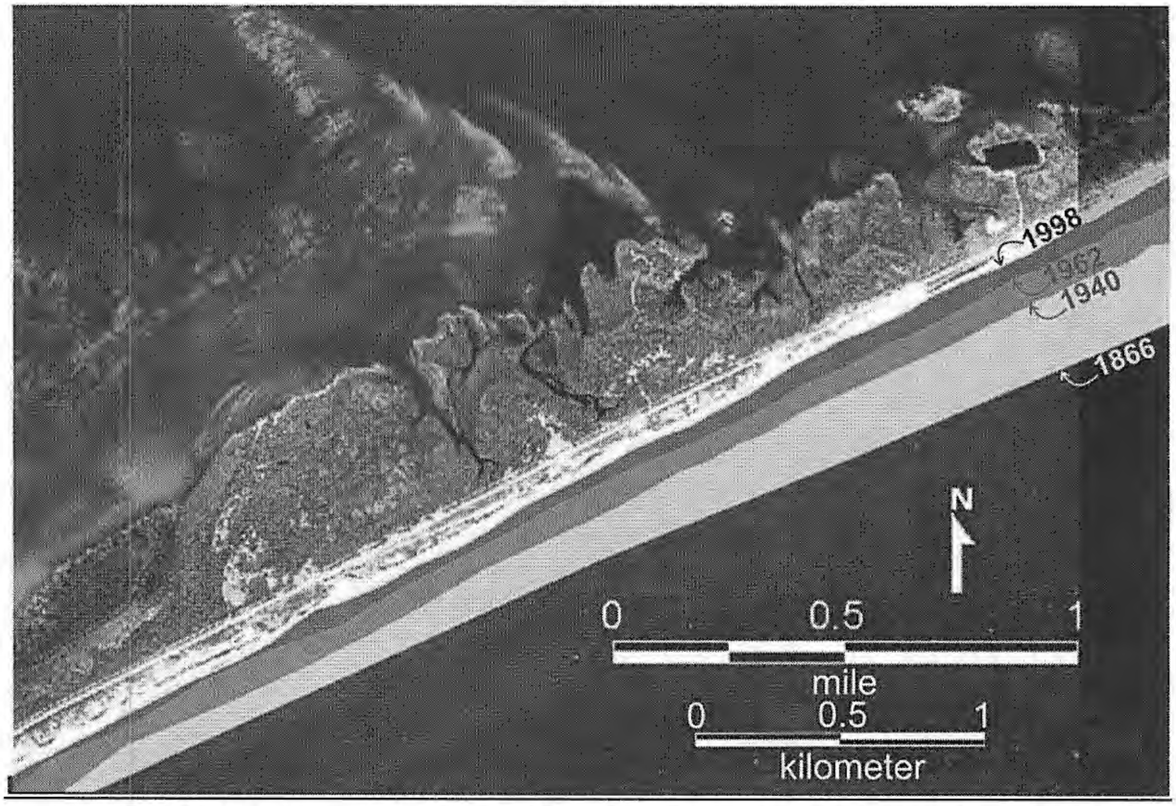


**Figure 1-29. Shoreline changes on Ocracoke Island are shown for a time period spanning 132 years (1866-1998). Yellow represents the amount of shoreline recession that occurred between 1866 and 1940; green represents the erosion between 1940 and 1962, and red represents the land lost between 1962 and 1998.**

In contrast to the longer-term changes of the Ocracoke Island shoreline (Figure 1-29), Figure 1-30 shows a dramatic change in the shoreline along the Chowan River that occurred in less than an hour during Hurricane Isabel on Sept. 18, 2003. At this locality, a 75-foot high bluff was severely eroded as a 6- to 8-foot storm surge rose against the bluff with waves produced by hurricane force winds as the eye of the hurricane passed slightly to the west of the Chowan River. The storm surge dropped and waves subsided as the eye of the storm moved north of the area. However, the bluff had receded up to 80 feet in less than an hour's time period (Figure 1-30B).

Shoreline changes are inevitable. While various methods are available to combat erosion and land loss, none are permanent solutions and all have significant environmental tradeoffs. Recognizing and understanding the complex causes and dynamic processes involved in shoreline erosion is the first step towards minimizing the impact of erosion and managing our shoreline resources and economic investments. Ultimately, to both preserve our coastal resources and maximize human utilization, officials must consider the dynamics of the total coastal system when developing long-term management solutions to shoreline erosion.

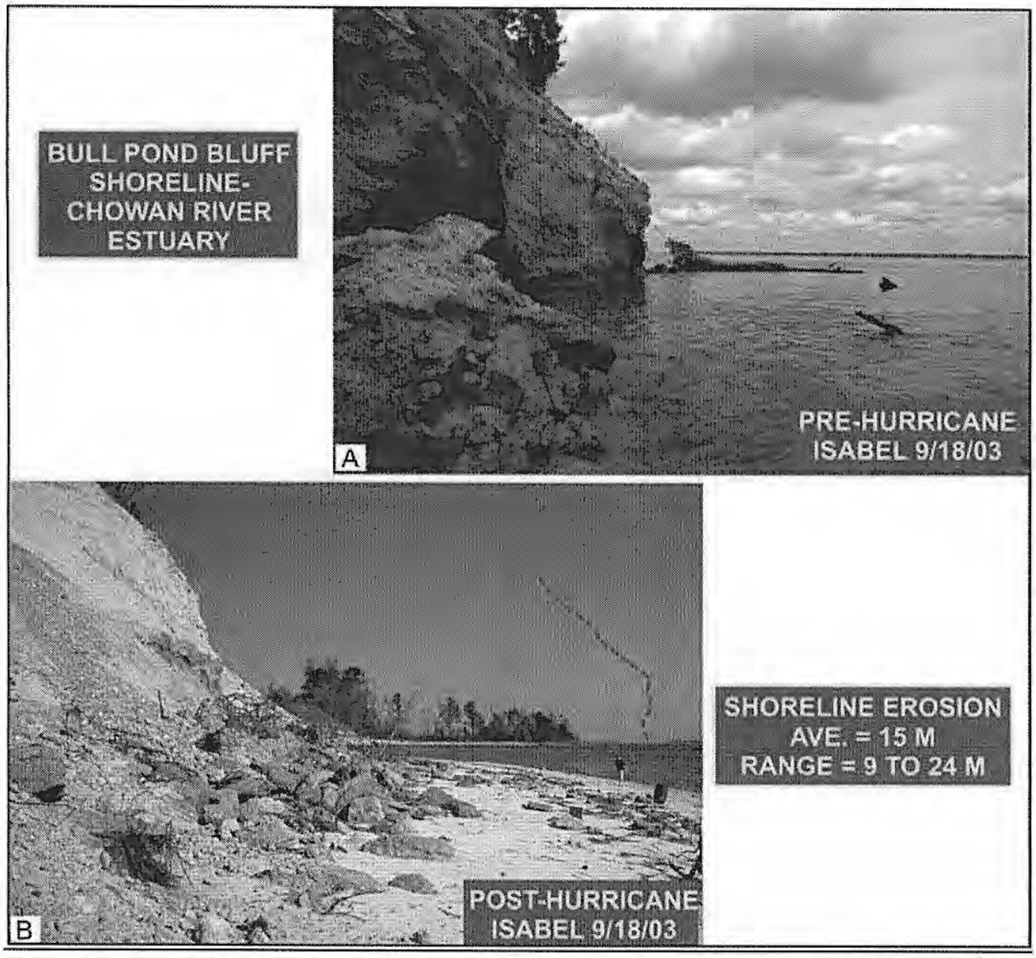


**Figure 1-30.** Two photographs of an eroding estuarine sediment-bank shoreline along the western side of the Chowan River. Panel A. Pre-Hurricane Isabel photograph was taken prior to the storm on Sept. 18, 2003. This ~75-ft high bluff consists of a lower clay bed (~30 ft thick) with an overlying sand bed (~45-50 ft thick). Panel B. The post-Hurricane Isabel photograph was taken on Oct. 6, 2003 from about the same location along the bluff shoreline as Panel A. The red dashed line in Panel A is in the same relative location as in Panel B. The average bluff shoreline recession was about 50 ft (range from about -30 to -80 ft) for the several segments of accessible bluff shoreline. Figures are the front and back cover of Riggs and Ames (2003).

## Student Learning Cycle

**Engage:**

Show students slides of Figures 1-29 and 1-30. Explain the difference in the rates of shoreline loss in these two examples. Because shoreline changes during a rising sea level are inevitable, what should humans consider in their decisions about living along shorelines?

**Explore:**

Materials Needed:

1 copy of Figures 1-4 and 1-29 per group
Rulers

Answer these questions in your group:

1. What was the change in population for Dare County between 1970 and 2000 (see Figure 1-4)?
2. Calculate the total percent increase and average annual rate of increase for the Dare County population from 1970 to 2000.
3. What are the problems of a rapidly increasing population on the barrier islands?
4. Use the scale in Figure 1-29 and calculate the average rate of shoreline recession from 1866 to 1998 at the location of the arrows.
5. At the rate of change that you calculated for #4, how many years will it be before the ocean shoreline has totally eroded through the island at the location of the arrow?

**Explain:**

Answers to group questions may vary because of the lack of sharp precision in the photos and the rulers. Talk about differences and the reasons for them. Reconcile differences in opinions through student discourse. Add any details you choose from the teacher background information.

**Extend:**

Find as much information as you can about Ocracoke Island. What is its population? How do you get to the island? What is the likelihood of a major increase in population? How do year-round residents make a living? How do the residents respond to predictions of hurricanes?

**Evaluate:**

Consider this statement: *For long-term success for both society and the coastal ecosystem, decision makers must face the inevitability of change and utilize the valuable coastal resources in ways that are in harmony with the energy and processes of the natural system.*

Discuss ideas for balancing the needs of society and the realities of the coastal ecosystem—particularly regarding development on the islands.

## Lesson Sixteen: Human Responses to Eroding Shorelines

Teacher background information:

The placement of buildings and roads should take into account the certainty of change in barrier island shorelines, as dramatically illustrated by the history of the Cape Hatteras lighthouse. The base of the original Cape Hatteras lighthouse, built in 1802, finally eroded into the sea in the 1970s. The present Cape Hatteras lighthouse was constructed in 1870 when it was approximately 1500 to 2000 feet inland of the ocean shoreline as indicated in Figure 1-31. This map of historic shorelines reflects a fairly constant rate of shoreline recession from 1852 to 1965 (113 years) for the area from Buxton to Cape Hatteras.

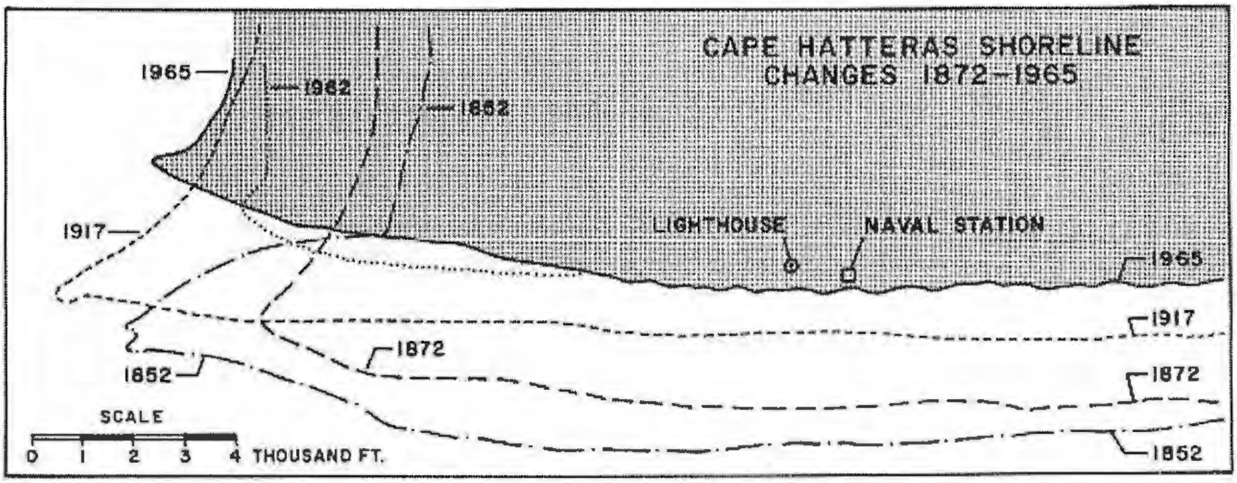


**Figure 1-31. This map of historic shorelines reflects a fairly constant rate of shoreline recession for the 113 years from 1852 to 1965 in the area from Buxton to Cape Hatteras. Figure is from Fisher (1967), who modified it from the US ACE (1963). Figure 6-3-1, p. 64 in Riggs and Ames (2003).**

Although the builders of the current lighthouse anticipated a very long life span for the structure, you can see from Figure 1-31 that the gradual rise in sea level and the regular impact of storms was sure to complicate those expectations. In fact, as the amount of shoreline erosion encroached upon the lighthouse, an extensive series of shoreline hardening structures (Figure 1-32) were built (steel groins, rock revetments, and many sandbag bulkheads), along with a series of beach nourishment projects, in desperate efforts to "hold the shoreline" and protect the lighthouse during the 1960s and 1970s.

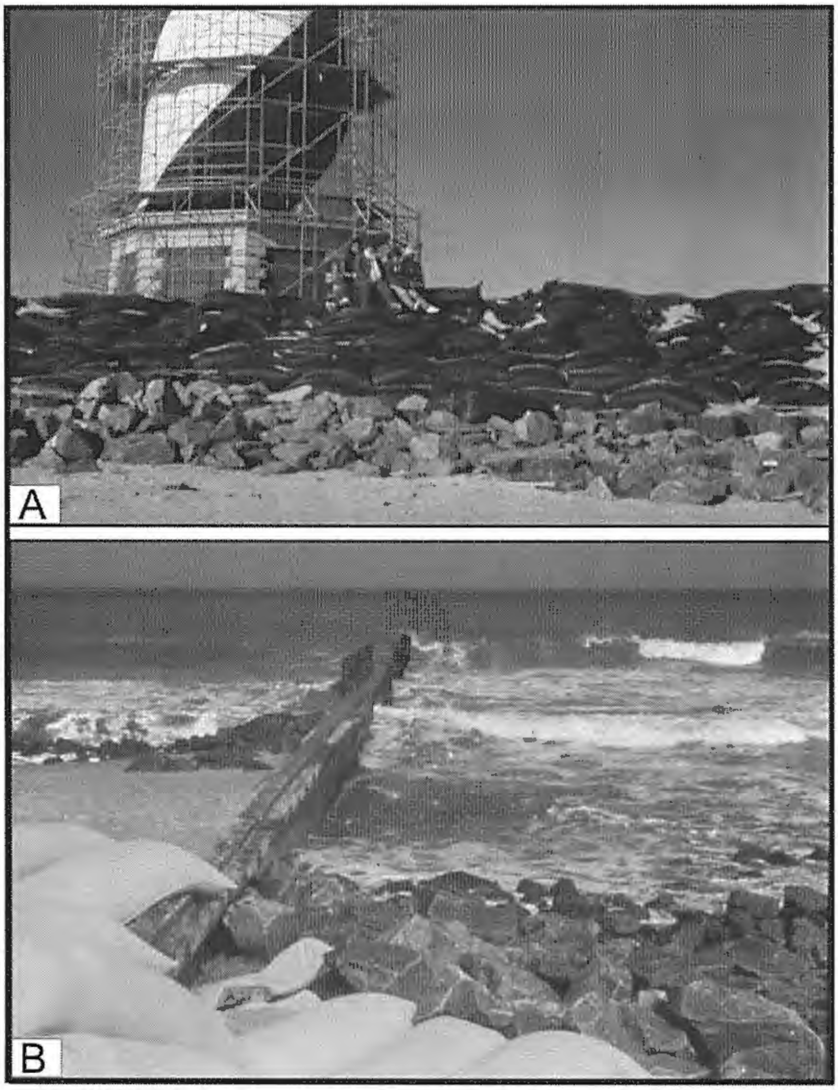


**Figure 1-32. Panels A and B. Photographs of the extensive effort to protect the Cape Hatteras Lighthouse from the encroaching Atlantic Ocean with massive hardened structures. These photos show a steel bulkhead, a steel groin, several rock revetments, and many layers of sand bags that have been used over decades in desperate attempts to "hold the line." Photographs are by S. Riggs.**

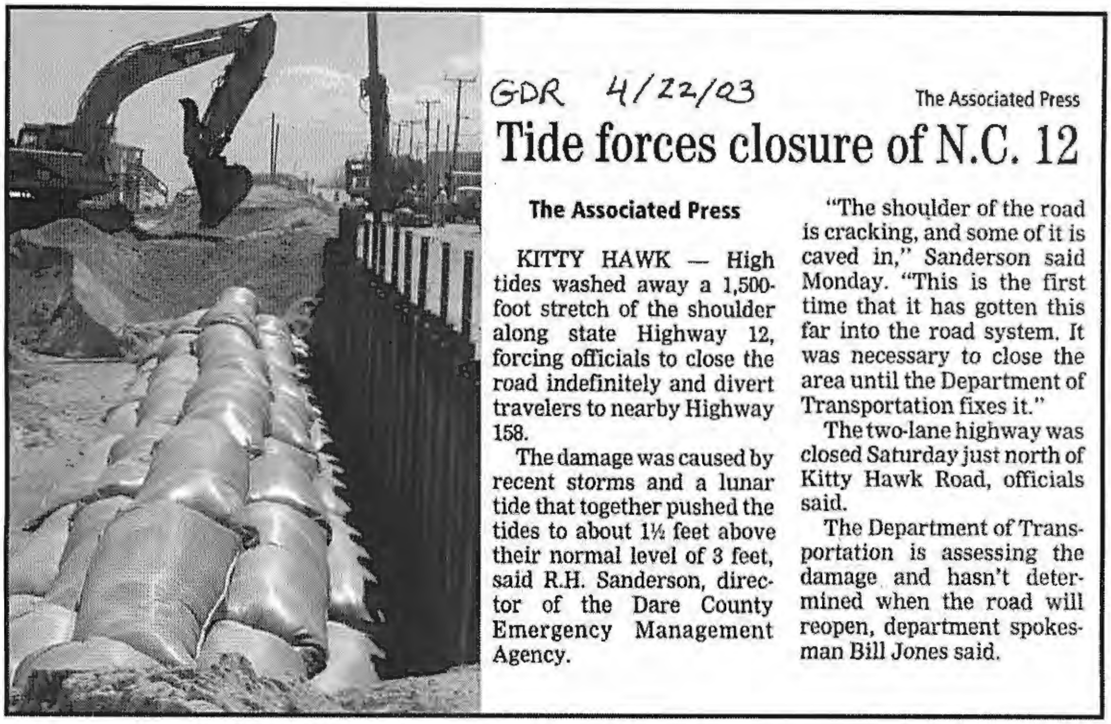
Several decades of heated debate took place during the 1980s and 1990s about the future of the Cape Hatteras lighthouse as it continued to be threatened by shoreline erosion. Many citizens wanted to preserve the structure at all costs, while others wanted to allow natural forces to take the lighthouse. The latter would provide a lesson about the constant change in the shorelines of barrier islands and the vulnerability of human-made structures built on those shorelines. Their rationale was that the loss of such a structure to the sea would prompt more careful consideration of construction policies on barrier islands.

The decision was made by the U.S. National Park Service and Cape Hatteras National Seashore to move the lighthouse in 1999 to a site inland of its original location. Figure 1-33 shows the lighthouse in its original position at the top left of the photo and a prepared roadway to the new site at the bottom right. Figure 1-34 shows the lighthouse in route to its new location further inland from the ocean.

**Figure 1-33. Cape Hatteras Lighthouse is being prepared for its move from the old threatened site adjacent to the rapidly eroding shoreline to a new inland site. Photograph is by the N.C. Department of Transportation.**

<u>Figure 1-34.</u> **Cape Hatteras Lighthouse is on its slow and deliberate move towards the new inland relocation site. Photo is by the N.C. Department of Transportation.**

The conflict continues between the natural processes of sea-level rise and coastal storms, causing the ocean to continue its erosional transgression on human infrastructure and houses. Figure 1-35 shows the N.C. Department of Transportation shoring up N.C. Hwy. 12 in Kitty Hawk. The photograph was taken on March 30, 2003 and the date of the newspaper article was April 22, 2003. It was not even a storm that took out this segment of N.C. Hwy. 12, but just an abnormally high spring tide.



GDR 4/22/03

The Associated Press

# Tide forces closure of N.C. 12

**The Associated Press**

KITTY HAWK — High tides washed away a 1,500-foot stretch of the shoulder along state Highway 12, forcing officials to close the road indefinitely and divert travelers to nearby Highway 158.

The damage was caused by recent storms and a lunar tide that together pushed the tides to about 1½ feet above their normal level of 3 feet, said R.H. Sanderson, director of the Dare County Emergency Management Agency.

"The shoulder of the road is cracking, and some of it is caved in," Sanderson said Monday. "This is the first time that it has gotten this far into the road system. It was necessary to close the area until the Department of Transportation fixes it."

The two-lane highway was closed Saturday just north of Kitty Hawk Road, officials said.

The Department of Transportation is assessing the damage and hasn't determined when the road will reopen, department spokesman Bill Jones said.

**Figure 1-35. A newspaper article documents damage to N.C. Hwy. 12 in Kitty Hawk with nothing more than an abnormally high spring tide, not a storm. This segment of beach has already lost the ocean front homes and is now working on the road, which has been repaired and rebuilt many times in the last decade. The photograph was taken on March 30, 2003 and the date of the newspaper article was April 22, 2003. Photograph is by S. Riggs. Article is used with permission of *The Daily Reflector*, Greenville, N.C.**

Estuaries constitute large portions of coastal systems and they also have shorelines. In fact, there are over 4,000 miles of estuarine shorelines in eastern North Carolina. Most of the estuarine shorelines behind the barrier islands and along the mainland shore of the large Pamlico and Albemarle Sounds are also characterized by severe rates of erosion (Figure 1-30).

As ever-increasing numbers of people and businesses move to the coastal region and more and more hotels, restaurants, and beach houses are built, decision makers have used many methods to deal with the problems of shifting shorelines. In some cases, they have chosen hard structures that were considered to be permanent solutions to coastal erosion. On the ocean shoreline, hardened structures such as those used around the Cape Hatteras lighthouse (Figure 1-32) were no longer allowed by the mid-1980s. However, no such rules have been put in place for the estuarine shoreline. This has resulted in the extensive use of hardened structures associated with most development (Figure 1-36).

Rock revetments, bulkheads, and other forms of shoreline hardening on eroding sediment-banks cut off the internal sand supply, and beach sands soon begin to disappear. The hardening of one piece of property along a shoreline will generally increase the rates of erosion on adjacent properties. This is the domino effect that usually forces the neighbors to begin hardening their shoreline, accelerating the rate of beach loss. Hardened shorelines will lose their sandy beach completely (Figure 1-36) unless their neighbors allow the adjacent shorelines to continue to erode.

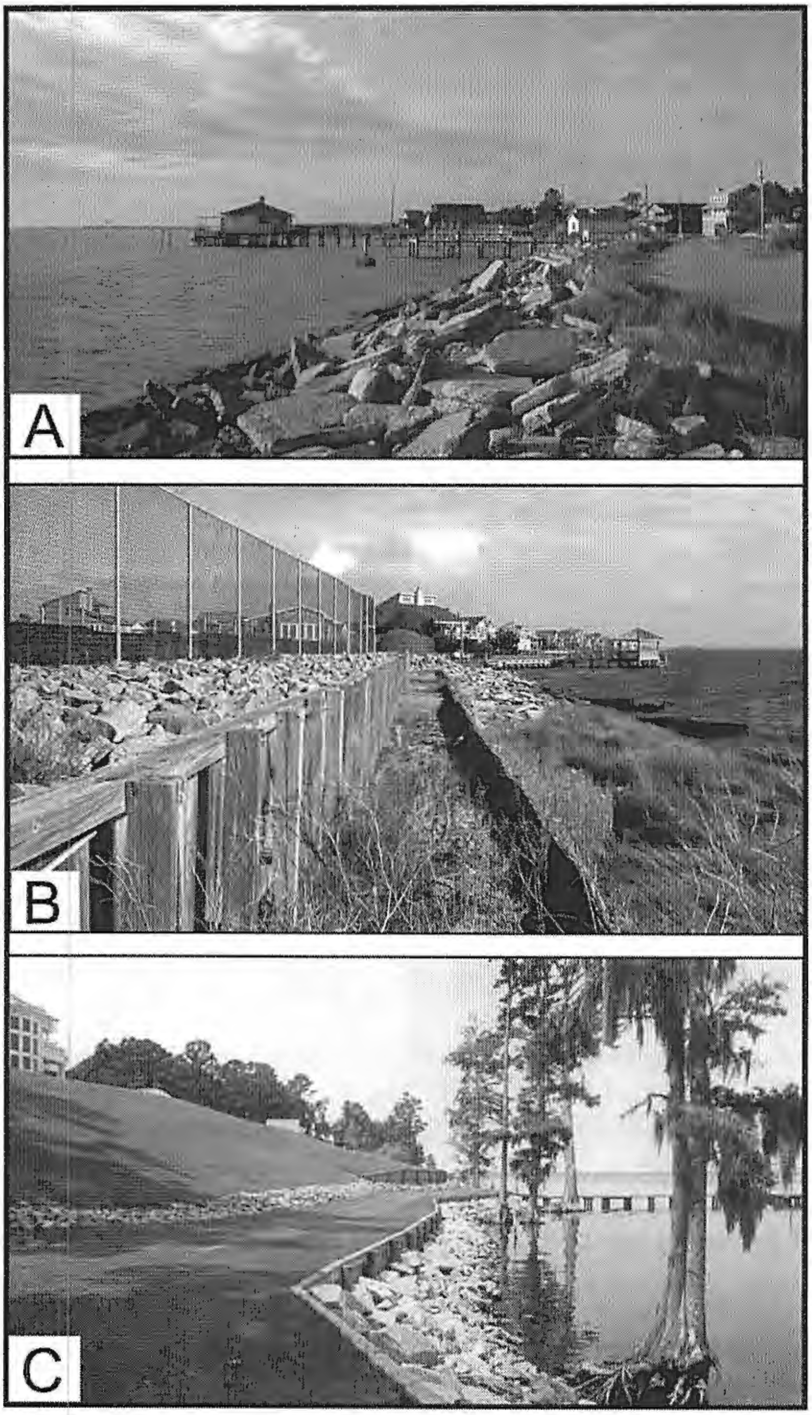


Figure 1-36. Hardened structures along the sediment-bank shorelines within the estuarine system were built in an effort to stabilize the rapidly eroding shoreline. Notice that there are no sand beaches in front of most stabilized estuarine shorelines. Panel A. Concrete rip-rap has been dumped multiple times along Sound Side Road on the back side of the barrier island at Nags Head. Panel B. Multiple layers of wooden groins, wooden bulkheads, and rock revetments have been emplaced to protect the tennis courts on the back side of the barrier island at Nags Head Cove. Panel C. The sediment bluff was terraced; steel bulkheads and rock rip-rap were emplaced along the shoreline at Mauls Point in the Pamlico River estuary. All photographs are by S. Riggs.

## Student Learning Cycle

**Engage:**

Show students slides of Figures 1-33 and 1-34. Ask why the Cape Hatteras Lighthouse had to be moved inland after so many years at its previous site? Show Figure 1-32. Ask why the bulkheads, rocks, and sand bags failed to protect the lighthouse?

**Explore:**

Materials Needed:

1 copy per group of these Figures: 1-30, 1-31, 1-35, and 1-36
Rulers

Have groups answer these question:

1. Notice the shoreline locations in Figure 1-31 relative to the location of the Cape Hatteras lighthouse in 1852, 1872, 1917, and 1965. Using the scale on the figure, measure the distance of the lighthouse to each of the 1852, 1872, 1917, and 1965 shorelines.
2. Calculate the change (in feet) and rate of change (in feet/year) in the shoreline in front of the lighthouse between 1852 and 1872, 1872 and 1917, and 1917 and 1965. Has the rate of shoreline erosion been constant through time or has it increased or decreased? Which of these time periods was probably the stormiest and which was a quieter period?
3. Calculate the average rate of change for the entire time period between 1852 and 1965. If the rate of change (in feet/year) continued from 1965 to the present, how far inland of the lighthouse would the shoreline be? Assume there are no hardened structures and that the number and intensity of storms continued at the same rate as before.
4. What caused the damage to N.C. Hwy. 12 in Figure 1-35?
5. This portion of the road is frequently under repair by the N.C. Department of Transportation. What do you think the eventual fate of the road is?
6. What are the advantages of shoreline hardening? What are the drawbacks of such "permanent" structures as shown in Figure 1-36? Are these structures really permanent? Explain.
7. Are there sand beaches in Figure 1-36? Explain the relationship between hardened shorelines and the loss of sandy beaches.
8. If a bulkhead were constructed in front of the high cliff in Figure 1-30, what changes in the beach would you predict?
9. If you removed the rock revetments and bulkheads from any of the estuarine shorelines in Figure 1-36, what changes in the shorelines would you predict to occur over time?

**Explain:**

Have students explain their answers. Help them to understand the effects of shore hardening structures on the sound side of the island.

**Extend:**

Have students design and conduct a simulation experiment to show the effect of waves on the shoreline adjacent to a section of shoreline with a bulkhead or other hardened feature. You may use a plastic shoe box, sand, water, a wooden block to represent a bulkhead, and a flat piece of wood with which to generate waves.

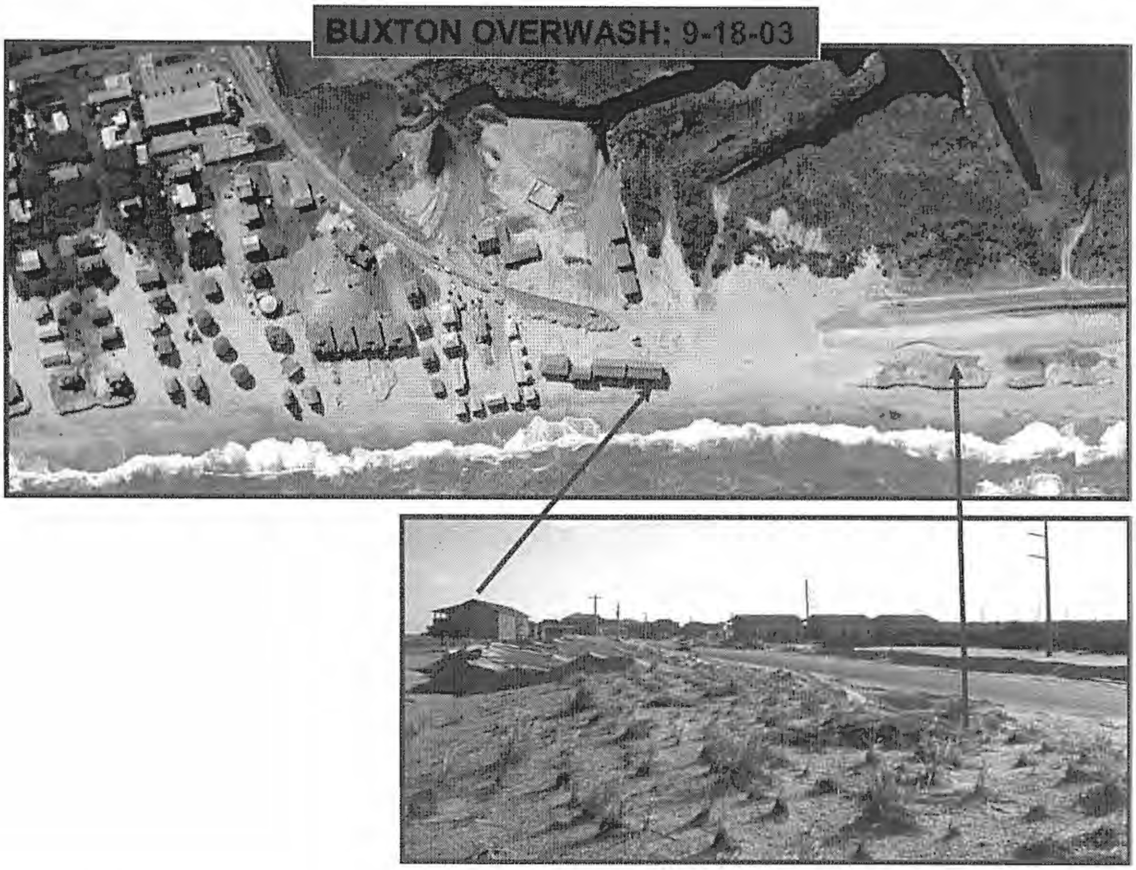
**Evaluate:**

List the different types of hardened structures that people use to prevent the erosion of the shoreline along their property. What effects do the hardened structures have on the shoreline where they are located and the shoreline adjacent to them?

## Conclusion of Part 1

As you have seen in *Part 1,* the dynamics of wind, water, and waves and the resulting change through time are dramatically illustrated on North Carolina's Outer Banks. There are many sites that illustrate the processes described in *Part 1* and the conflicts that occur when humans, their activities, and their structures face the unrelenting forces of nature. The relationships between natural change and human activities are explored in *Part 2.* You are invited to join the Sea-View team in an investigation of a particularly interesting location between Avon and Buxton, a narrow strip of sand that provides a vital north-south transportation link. Storms that batter this stretch of land show no regard for the needs of the humans who depend upon N.C. Hwy. 12 to get them from one end of the Outer Banks to the other.

# PART 2: AVON-BUXTON: "GOING-TO-SEA HIGHWAY



Panel A. NOAA. 2003 post-Hurricane Isabel aerial photograph of Buxton Village and Cape Hatteras National Seashore, just south of the Sea-View site. Panel B. Ground photograph of the remnant barrier-dune ridge (foreground), the overwash deposit, and the overwash sand that was bulldozed back to rebuild the barrier-dune ridge. Photograph is by S. Riggs.

## Teacher Background Information:

### The Issue

At the Avon-Buxton site the Sea-View team encountered eroding ocean and estuarine shorelines on an extremely narrow, overwash-dominated barrier island. N.C. Hwy. 12, located along the back side of the island, is a critical transporation link that serves residents and businesses further south on the Outer Banks. Based upon the natural dynamics of this barrier island segment and the importance of N.C. Hwy. 12 to the regional economic base, there are a number of crucial conflicts that must be understood.

The natural barrier island dynamics do not necessarily work in response to the needs and desires of humans who use the islands for recreation, livelihood, or inspiration. Sea-level rise continues. Storms occur with regularity. The islands move in response to energy of wind and waves—regardless of human structures that might be affected. These natural processes inconvenience human inhabitants, many of whom would prefer to control the processes, to keep things the same. The new four-lane bridges and highways to the Outer Banks are bringing record growth. Easier access promotes increased growth and development, providing economic advantages, but also complicating the task of retaining the natural barrier island processes that are essential for the long-term health and maintenance of this high-energy coastal system. As long as the new growth and development ignore the dynamic processes and the inevitability of change, there will continue to be major conflicts between the natural barrier system and the human superstructure perched on top of and around the barrier islands.

### Conflicts

#### 1. Barrier island dilemma: growth, development, and storm evacuation.

Ever increasing growth and development of the Outer Banks have boosted both the population and economy of isolated communities scattered among the low and narrow barrier islands. With growth and development comes the necessity to evacuate the increased numbers of visitors and residents during the annual hurricane season. The only evacuation route is N.C. Hwy. 12, the road located on extremely narrow segments of the barrier islands that is continuously vulnerable to both overwash and inlet dynamics. It routinely becomes impassible and occasionally is destroyed by high-energy storm surges and the resulting shoreline erosion. Under current policy, N.C. Hwy. 12 is maintained at a very high cost in hopes of maintaining a reliable transportation link to and from the communities along the islands.

#### 2.High ocean and estuarine shoreline erosion rates and island narrowing.

The natural processes of storms and sea-level rise cause shoreline erosion at substantial rates. The ocean shoreline in the Avon-Buxton area is eroding at an average rate of -8.1 feet/year with local areas eroding at average rates up to -10.5 feet/year. The estuarine shoreline is receding at an average rate of -2.6 feet/year with local areas receding at average rates up to -18.6 feet/year. Thus, the island is rapidly narrowing, forcing the relocation of N.C. Hwy. 12 further west until it is, in some places, now located adjacent to the Pamlico Sound shoreline. This complicates both the short-term maintenance and long-term survival of this critical transportation link essential for the economy.

### 3.Barrier-dune ridge construction.

The current practice employed by N.C. Department of Transportation is to build and maintain barrier-dune ridges along the narrow sections of barrier islands (such as the Avon-Buxton site) to protect N.C. Hwy. 12. The intended purpose is to prevent storm overwash from taking place and to prevent the opening of new inlets through the islands. The unintended consequence is the severe narrowing of the island in response to ongoing erosion on both sides of the barrier and the lack of natural sand transport across or through the island, processes that would naturally build elevation and width of the island along the sound side. Without periodic sand renewal along the backside of the barrier, estuarine shoreline erosion increases, and those island segments could eventually collapse and disappear, particularly in light of ongoing sea-level rise.

### 4.The future of N.C. Hwy. 12: Continued maintenance with beach nourishment and barrier dune ridges or beach hardening.

Policy makers are desperately trying to consider mechanisms to maintain N.C. Hwy. 12 on land. All alternatives are costly and they all have advantages and disadvantages. Previously, there has been adequate space to successfully relocate the road westward after major storms. In many places, however, there is no longer adequate upland space for continued movement. Several beach nourishment projects—pumping sand onto the beach in an attempt to minimize the effects of storm surges—have been unsuccessful. This coast has very high energy with very little high quality beach sand available, making the cost of beach nourishment very high with little potential for success. Beach hardening, a strategy that is currently prohibited in North Carolina, uses hard structures (bulkheads, rock revetments, groins, etc.) in an attempt to hold back the force of the ocean during storms. Evidence shows that these types of engineering approaches may destroy the sand beach resource in such high energy coastal systems.

### 5.The future of N.C. Hwy. 12: Alternatives to a land-based transportation route with back-barrier causeway and/or ferries.

Other options would be to move the road off the barrier island and build a back-barrier causeway. This would provide a transportation link less subject to destruction in storms and allow barrier island dynamics associated with inlets and overwash to continue naturally building island elevation and width as extensive marsh platforms on the sound side. Another alternative is expanding the ferry system to transport people across areas in which the highway is particularly vulnerable.

## The Avon—Buxton Site

Figure 2-1 is a 1998 aerial photograph of the Avon-Buxton segment of the Outer Banks showing the location of the Sea-View site. Figure 2-2A is a 1992 oblique aerial view and Figure 2-2B is a 1999 aerial photograph of the Avon-Buxton site on Hatteras Island. These figures demonstrate how narrow the Avon to Buxton coastal segment is. It is a classic overwash barrier island that is basically sediment poor (relatively small quantity of available sand) and has the highest wave energy along the U.S. Atlantic coast. Consequently, the beach tends to be narrow and steep with coarse gravelly sand sediment. (See Table 2-1 in Lesson 2).

In addition, the Avon-Buxton area has extremely high ocean shoreline erosion rates that regularly threaten N.C. Hwy. 12 and other ocean-front properties, including the Cape Hatteras Lighthouse. Beginning in the late 1930s, and particularly since the 1962 coastal storm, reconstruction and maintenance of ever higher and increasing numbers of the temporary barrier-dune ridges have been built to protect N.C. Hwy. 12. This practice has significantly changed the physical processes and responses along this barrier island segment.

Because the island is narrow and the ocean shoreline is severely receding, N.C. Hwy. 12 has been moved numerous times (Figure 2-2A) in the last 40 years, with the latest move in response to Hurricane Dennis in 1999 (Figure 2-2B). N.C. Department of Transportation continuously rebuilds and maintains large barrier-dune ridges in an effort to protect N.C. Hwy. 12 and stop shoreline recession. This effort also eliminates the processes of barrier island overwash and inlet formation, essential for building island width and elevation. No matter how hard N.C. Department of Transportation tries, the barrier dune ridge is ultimately breached by a large storm or series of storms. If such a storm has opened an inlet, state workers rapidly fill the inlet and rebuild barrier-dune ridges. If the storms only produce major overwash fans across the island, the overwash sand is immediately pushed back onto the ocean side to rebuild the dune ridges. Thus, if the barrier dune ridge is in place, sand does not naturally move toward the sound side where it would build elevation and width to the island and produce sand shoal platforms for establishment of marsh grasses.

Figure 2-3 shows the change in ocean shoreline from the 1852 survey to the 1998 aerial photograph that has been georeferenced to the same scale as the 1852 survey. Notice that the N-S island segment is today only ~1/3 the width it was in 1852, and the island has moved generally westward through time. The N.C. Division of Coastal Management has measured the average erosion rates for a 52-year period from 1946 to 1998 of -8.8 feet/year with the central portion eroding at rates up to -10.5 feet/year. Based upon studies by the authors, the estuarine shoreline has been receding for the period from 1962 to 1998 at an average rate of -2.6 feet/year with local areas receding at average rates up to -18.6 feet/year for brief time periods. Much of the latter erosion is probably in direct response to elimination of overwash and inlet processes to protect N.C. Hwy. 12 with construction of barrier-dune ridges.

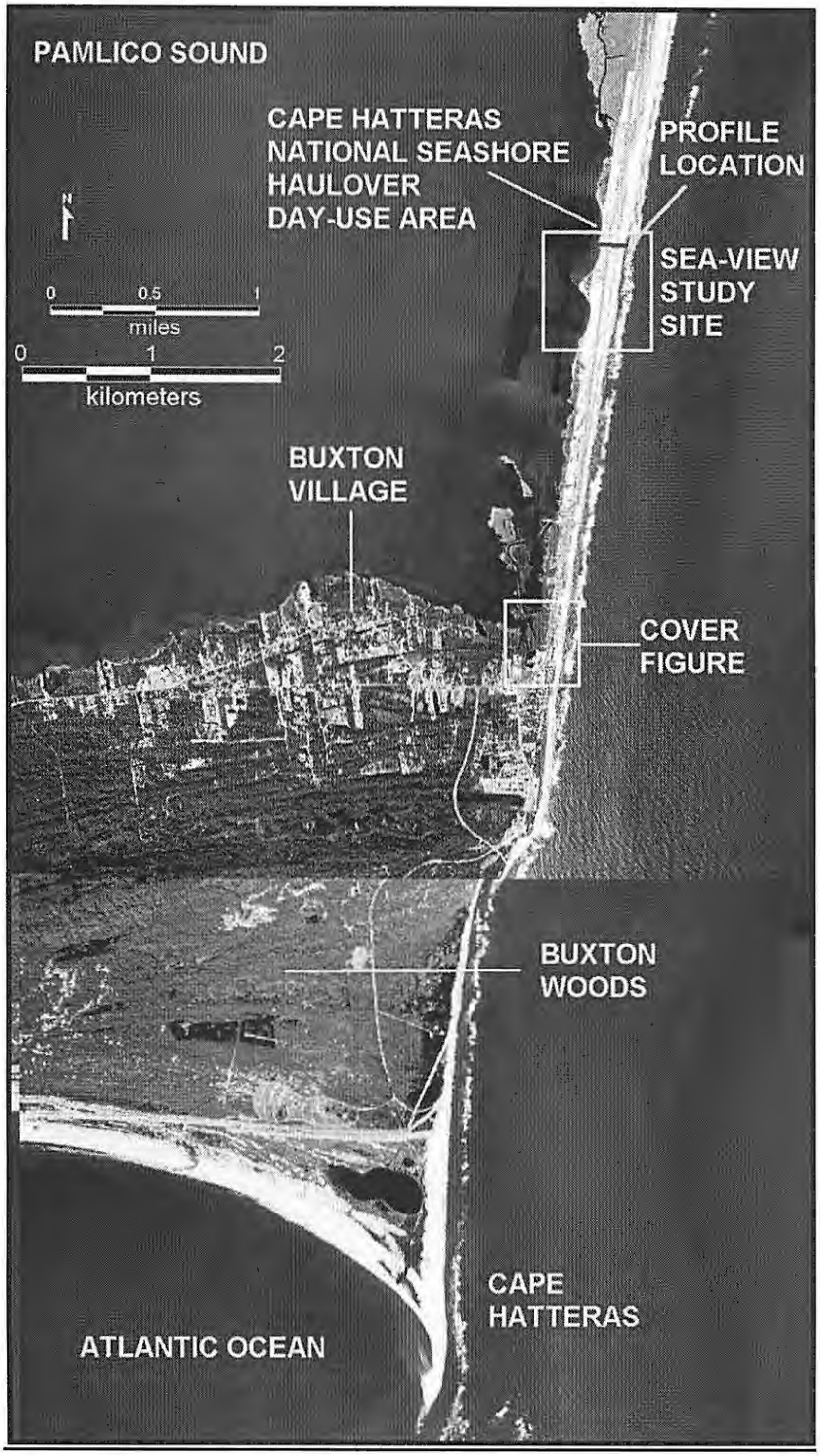


**Figure 2-1. A 1998 aerial photograph shows the Avon-Buxton barrier island segment with Buxton Village and the extensive system of beach ridges that constitute Buxton Woods on the bottom of the photo. Figure is modified from Figure 8-2-6, p. 86 in Riggs and Ames (2003).**

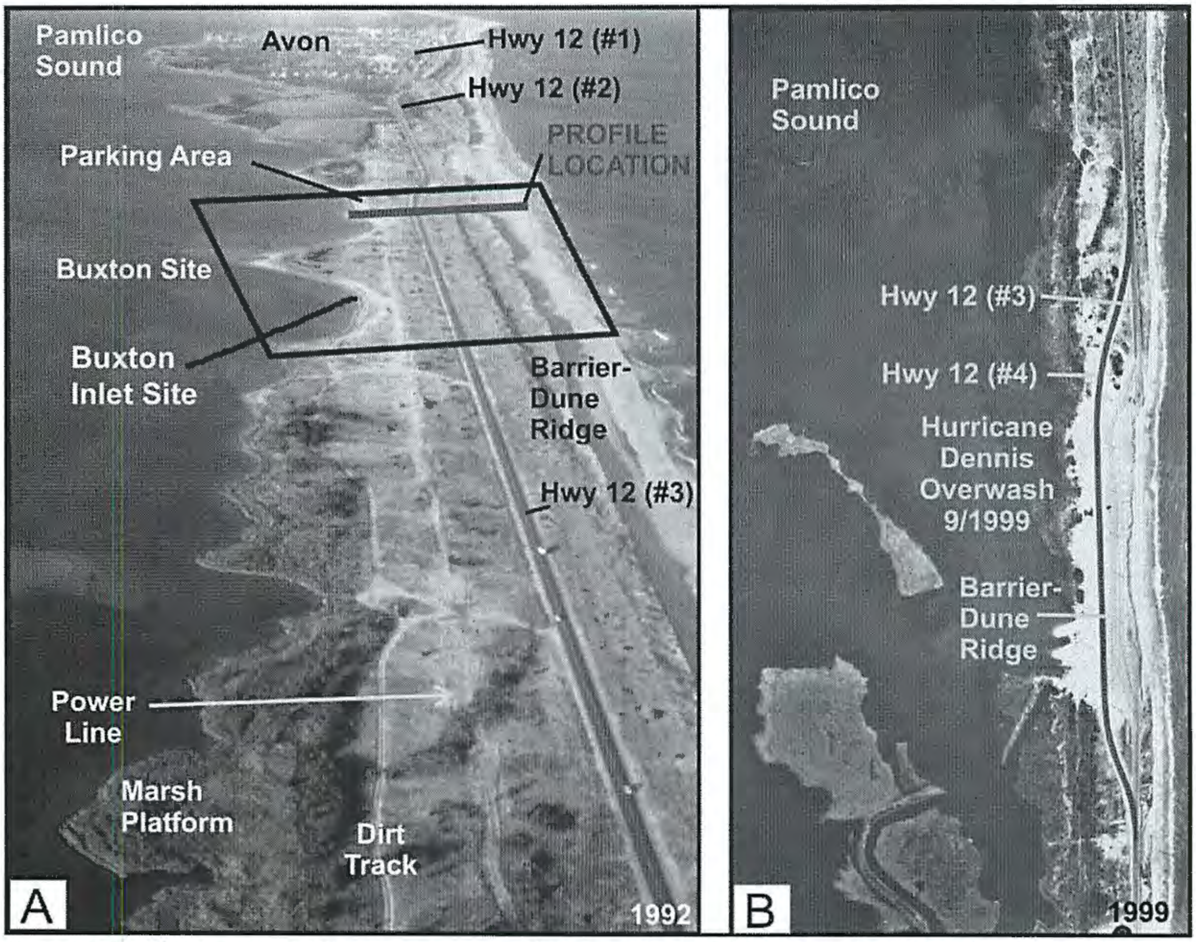


**Figure 2-2. The Buxton Inlet site is one of the series of N.C. Hwy. 12 DOT "hot spots" where the coastal highway is in serious jeopardy. Panel A. A 1992 oblique aerial photograph shows the 1992 location, as well as two former locations of N.C. Hwy. 12 and the double barrier-dune ridges along the ocean beach built to protect the highway. The most seaward ridge has been severely eroded and the small portion that remains is steeply scarped. The two former road locations were straight along the barrier island and were subsequently moved towards the estuary as shoreline erosion destroyed road segments through time. The red line across the island is the location of the topographic profile in Table 2-1. Panel B. A 1999 aerial photograph shows a new fourth location of Hwy 12 in response to a major overwash event associated with Hurricane Dennis in 1999. Figure 8-2-5, p. 85 in Riggs and Ames (2003).**

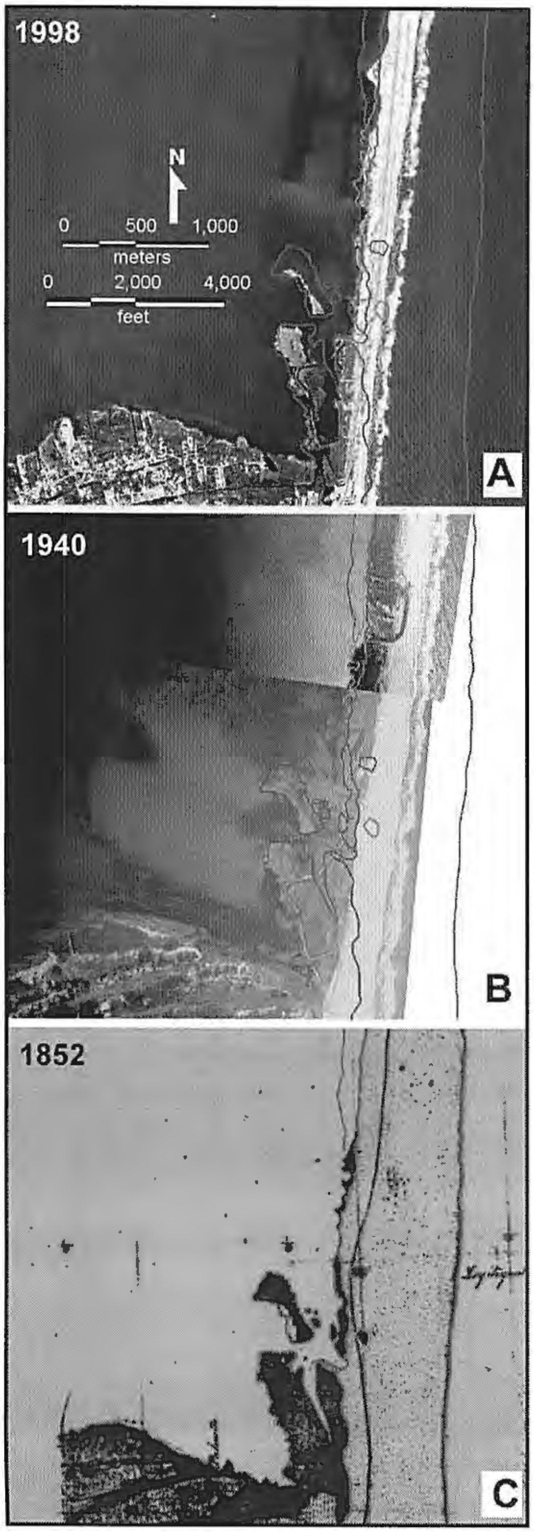


Figure 2-3. A three-panel time series analysis of georeferenced aerial photographs shows the net change in both island location and width between 1852 and 1998 for the Buxton-Avon area. Panel A. This 1998 aerial photograph shows only a small portion of the original island (purple lines) remaining after 146 years of ocean shoreline erosion. Panel B. This 1940 photograph is the oldest known aerial for this area and shows major ocean shoreline recession since 1940. Panel C. This 1852 topographic survey shows an island that was about three times wider than in 1998 with the ocean shoreline significantly east of its present location.

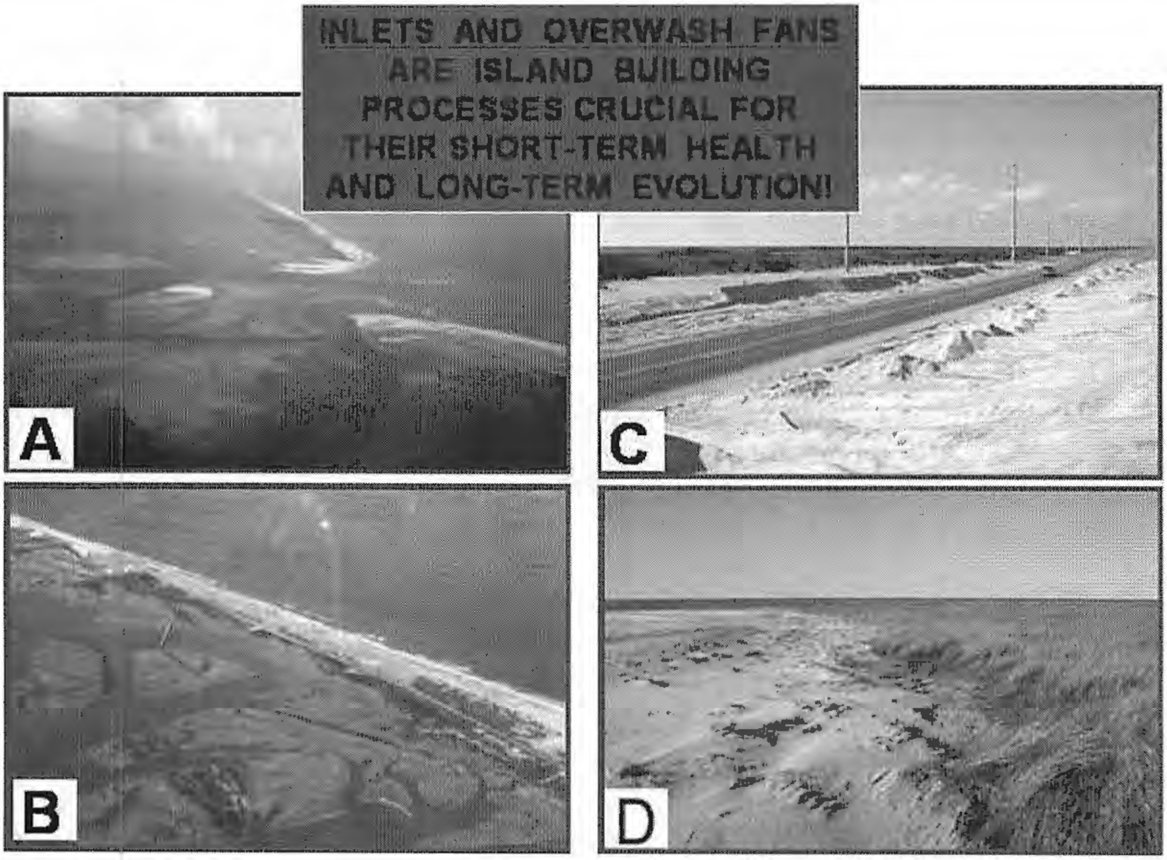


Figure 2-4. Inlets and overwash fans are critical barrier island building processes that are crucial for their short-term health and long-term evolution. Panel A is an oblique aerial photo of the active New Drum Inlet on Core Banks with a major flood-tide delta formed on the backside of the barrier. Photo is by D. Heron. Panel B is a 1992 oblique aerial photo of New Inlet on Pea Island that closed naturally in 1945 and shows the extensive salt marsh that has grown on the shallow sand shoals of the flood-tide delta since the inlet closed. Photo is by S. Riggs. Panels C and D are 2003 ground photos of major overwash fans that took place during Hurricane Isabel. In Panel C storm overwash carried sand over the island just south of the Sea-View site and deposited ~3 feet of sand across N.C. Hwy. 12 and into the adjacent shrub-scrub zone. In Panel D storm overwash carried sand across the island and deposited up to 3 feet of sand in marsh. Because of the increased elevation in the marsh, the area will revegetate as shrub-scrub. Photos are by S. Riggs.

On narrow sediment-poor barrier islands such as the Avon-Buxton segment, two basic processes are critical for both the short-term health and the long-term evolution of the barrier island: inlet formation and island overwash (Figure 2-4). These processes are crucial for building island elevation and width in a rising sea level situation, as presently exists in the coastal region of northeastern North Carolina. As sea level rises, storms erode the ocean shoreline (Figure 2-3). In order for a barrier island to survive in this situation, the back barrier must receive sand that increases both the width and elevation. The addition of back-barrier sand allows the island to move upward and landward in response to ongoing sea-level rise.

## Inlets

The formation of inlets along the Outer Banks is a natural process that has been occurring as long as the barrier islands have been in existence. Aerial photos and maps dating back to the late 16th century show a history of inlets that have formed as a result of storm activity; some still exist and others have closed as a result of natural processes or human intervention.

During the Ash Wednesday Nor'easter in 1962, Buxton Inlet opened in response to a combination of ocean shoreline recession and storm surge overtopping the island. Buxton Inlet (Figure 2-5-1962) finally broke through the island in a particularly weak spot in the Avon-Buxton barrier segment that had been severely modified with a canal (Figure 2-5-1940). Since the inlet did not close down during the post-storm period, a wooden bridge was constructed across the inlet for N.C. Hwy. 12 (Figure 2-6A). However, the bridge was taken out by another nor'easter in early December 1962 (Figure 2-6B). This prompted the N.C. Department of Transportation to initiate a dredging program to permanently close the inlet during the first two months of 1963 (Figure 2-6C and D). However, during the 10 months that Buxton Inlet was open, it was able to build a small flood-tide delta on the Pamlico Sound side of the barrier (Figure 2-5-1963).

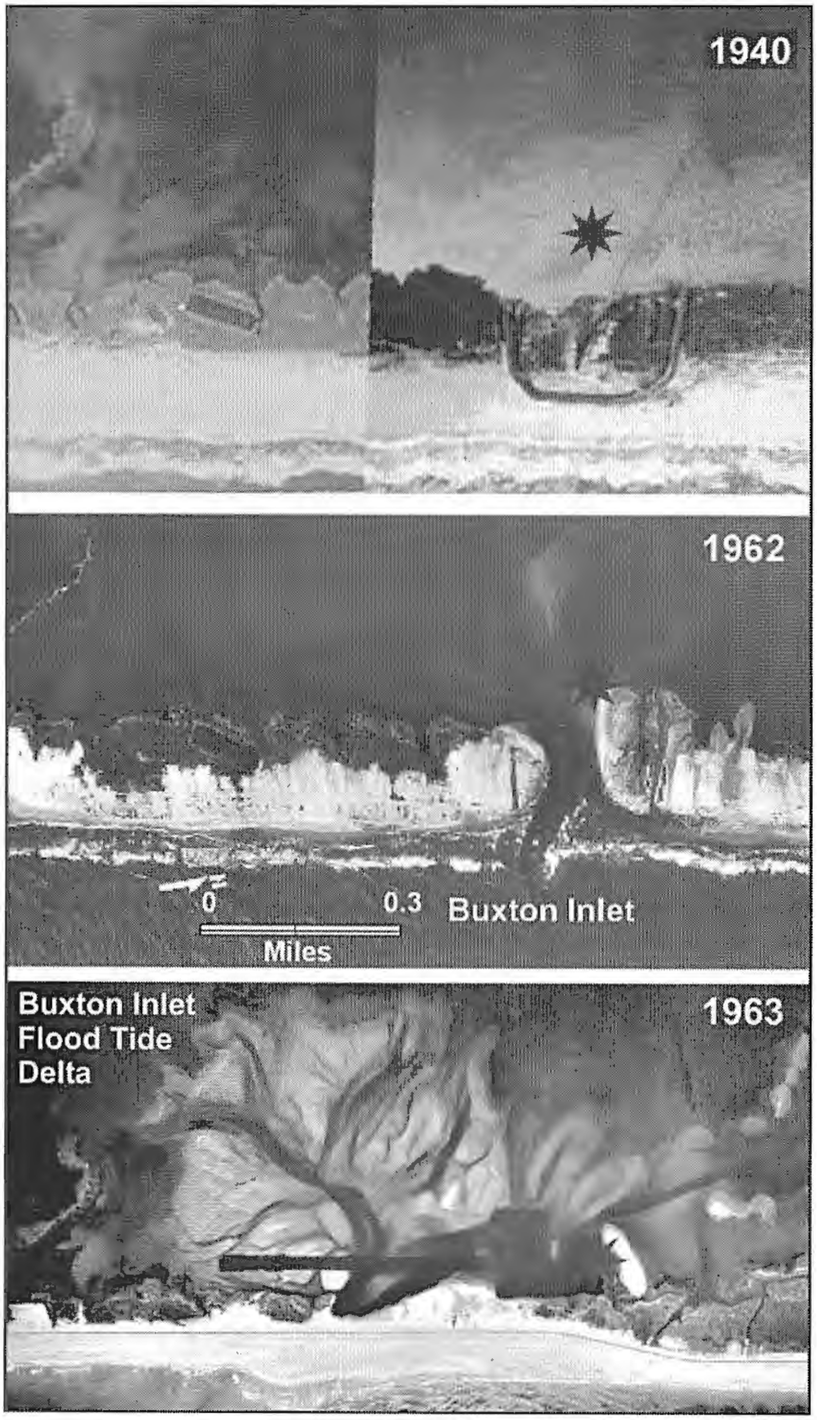


**Figure 2-5.** A georeferenced set of aerial photographs shows the location, development, and closure of Buxton Inlet. Panel-1940. The photograph shows a U-shaped dug canal and dike around a dredged boat channel and harbor at the exact spot that Buxton Inlet will open in 1962 (red star). Panel-1962. The photograph was taken in March 1962 after the Ash Wednesday Nor'easter opened Buxton Inlet and caused extensive overwash. Panel-1963. The photograph was taken after Buxton Inlet was closed in February 1963 and shows the small flood-tide delta that had formed during the ten months the inlet was open.

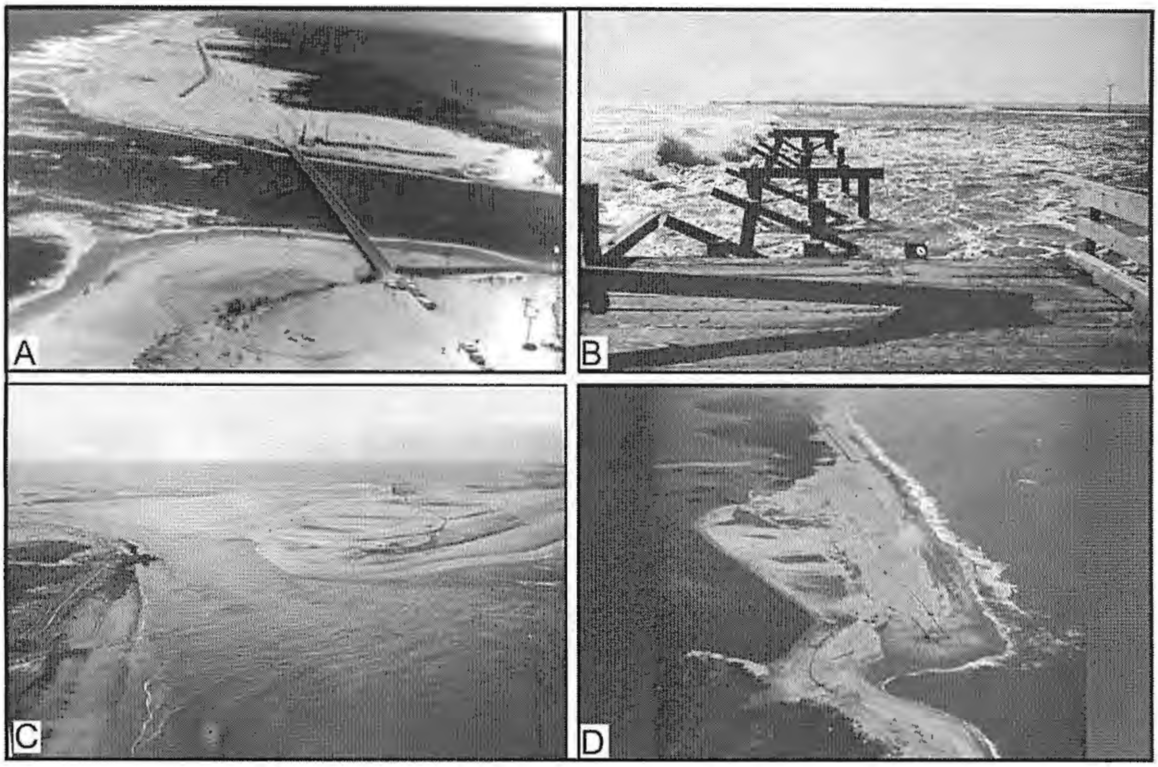


**Figure 2-6. A four-part photo series shows the history of Buxton Inlet which opened in the Ash Wednesday Nor'east storm in March 1962. Panel A. An oblique aerial photograph looking south shows the active inlet with a wooden N.C. Hwy. 12 bridge across it. Photograph is by Cape Hatteras National Seashore personnel. Panel B. A nor'east storm in early December 1962 took most of the bridge out. Panel C. An oblique aerial photo looking west was taken on January 29, 1963 and shows the dredge pumping sand from the sound side into the inlet. Panel D. An oblique aerial photo looking north was taken on February 21, 1963 when the inlet was finally closed. Photographs in Panels B, C, and D are from the U.S. Army Corps of Engineers (1963).**

Isabel Inlet, like Buxton Inlet, opened in response to a major storm (Hurricane Isabel that came ashore on September 18, 2003). Conflicts between natural processes of storms and their effects upon barrier islands on one hand and the needs of human inhabitants on the other hand occur with regularity on the barrier islands. After Buxton Inlet was closed in 1963, the management decision by different stakeholders was to secure the islands by constructing bigger and more extensive barrier-dune ridges. However, as fast as the barrier-dune ridges were rebuilt, the next series of storms would take them down. Buxton Inlet was not allowed to reopen, but at a great cost in a continuing effort to protect this road segment.

On September 18, 2003, Hurricane Isabel created a new inlet on Hatteras Island between

Frisco and Hatteras Village (Figure 2-7). This new inlet cut highway access for residents to the southwest of the inlet. The location of Isabel Inlet was very similar to Buxton Inlet. They are both sediment-poor island segments that are severely eroding on both the ocean and estuarine shorelines, resulting in net island narrowing. Ultimately both of these segments will narrow to the point where they will collapse again with the formation of inlets. They desperately need inlets and the deposition of new back-barrier sand bodies to constructively increase island width and elevation. Because both inlets were closed almost immediately, these island segments did not benefit from the construction of back-barrier flood-tide deltas, which take a few years to develop. Thus, both areas are still in need of an inlet and are extremely vulnerable to future inlets.

In contrast to Buxton and Isabel Inlets, New Inlet on Pea Island opened and closed periodically since the 1650s. It was last opened in the early 1930s and closed naturally in 1945. During the various times that New Inlet was open, a very extensive flood-tide delta was formed behind the Pea Island barrier. Since the last closure in 1945 the flood-tide delta sand shoals have evolved into a vast system of salt marshes as indicated in Figure 2-8. This island segment is extremely wide with a major sand base upon which the barrier can migrate upward and landward through time in response to the ongoing rise in sea level.

Thus, the New Inlet segment of Pea Island is fairly healthy and only needs overwash now to give the island some more elevation. However, this is not presently in the management plans. With the paving of N.C. Hwy. 12 in the late 1950s and early 1960s, barrier-dune ridge construction became the dominant management priority to protect the highway from both overwash and the formation of another "New Inlet." The 1932 aerial photograph shows a small, but active multi-channeled inlet with extensive back-barrier sand shoals that form the flood-tide delta and give the island tremendous width (Figure 2-8B). The 1992 oblique aerial photo shows that the entire flood-tide delta system has evolved into a vast salt marsh system (Figure 2-8C).

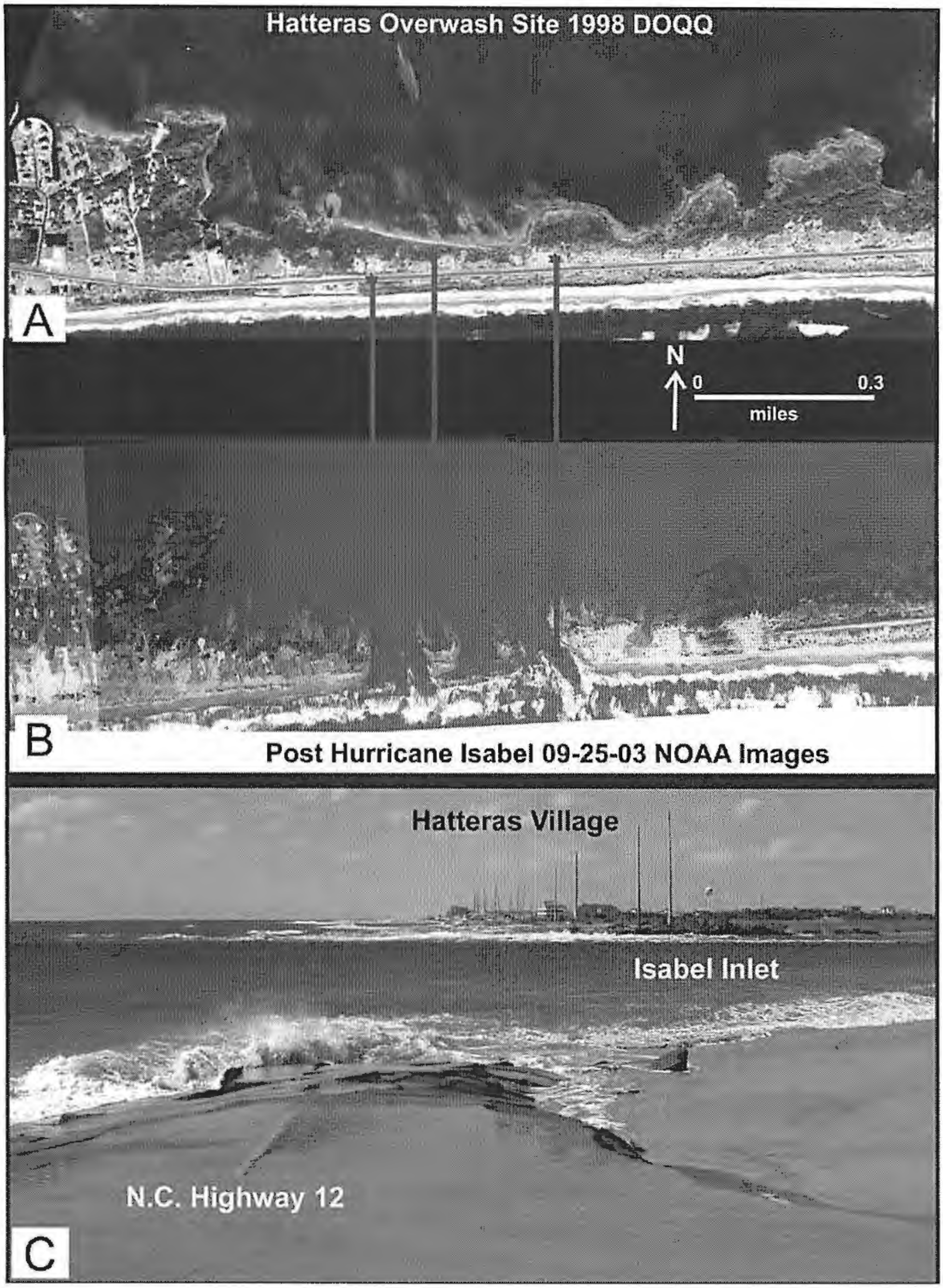


Figure 2-7. Panel A. A 1998 pre-Hurricane Isabel aerial photograph of a portion of Hatteras Island shows the future location of Isabel Inlet. Panel B. A 2003 post-Hurricane Isabel aerial photograph of the same portion of Hatteras Island shows the three channels of Isabel Inlet that opened on September 18, 2003. Panel C. A ground photograph looks SW across Isabel Inlet towards Hatteras Village. Notice the yellow center line of former N.C. Hwy. 12 "going-to-sea." Photograph is by S. Riggs.

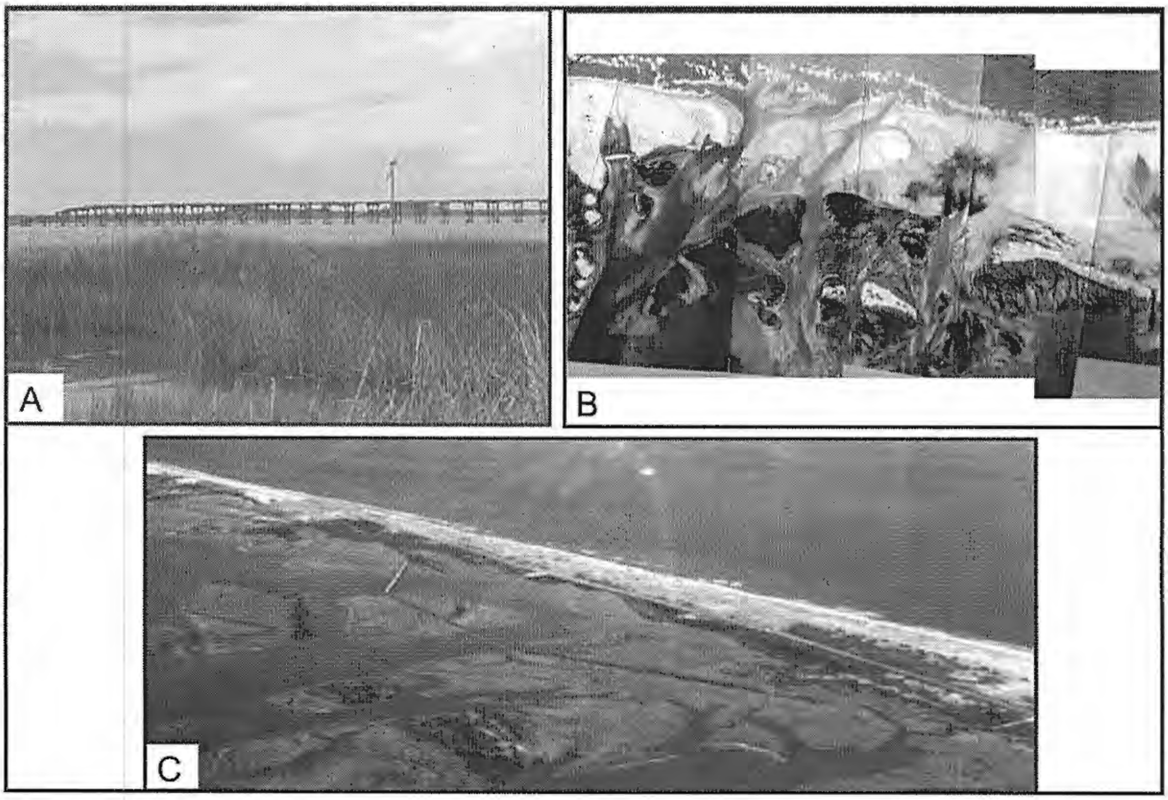


**Figure 2-8. Panel A. A 2001 photograph of the New Inlet flood-tide delta sand shoals that have evolved into extensive salt marsh after the inlet closed naturally in 1945. Notice the remnants of a wooden bridge built across New Inlet just before the inlet closed, when the bridge was abandoned. Photograph is by S. Riggs. Panel B. This 1932 aerial photograph shows a small, but active, multi-channeled New Inlet with a prominent flood-tide delta. Aerial Photograph is from the U.S. Army Corps of Engineers, Field Research Facility. Panel C. This 1992 oblique aerial photo shows the New Inlet flood-tide delta sand shoals. The bridge remnant is visible in the photograph. Photograph is by S. Riggs.**

## Overwash

Overwash processes take place during any storm when the storm surge is high enough that it can overtop the barrier island (Figure 2-5-1962). As the storm tide rises above the beach berm, storm water begins to flow across the island carrying large quantities of beach sand that is deposited as large sediment fans in the scrub-shrub and platform marsh zones and sometimes as sand shoals into the back-barrier estuary (Figure 2-9A). The volume of new sand depends on the size of the storm and resulting overwash event, but individual overwash fans commonly raise the island elevation by a meter or more and increase the width by hundreds of meters. These new sand bodies are quickly revegetated by the barrier island plants that are adapted to this process of frequent burial.

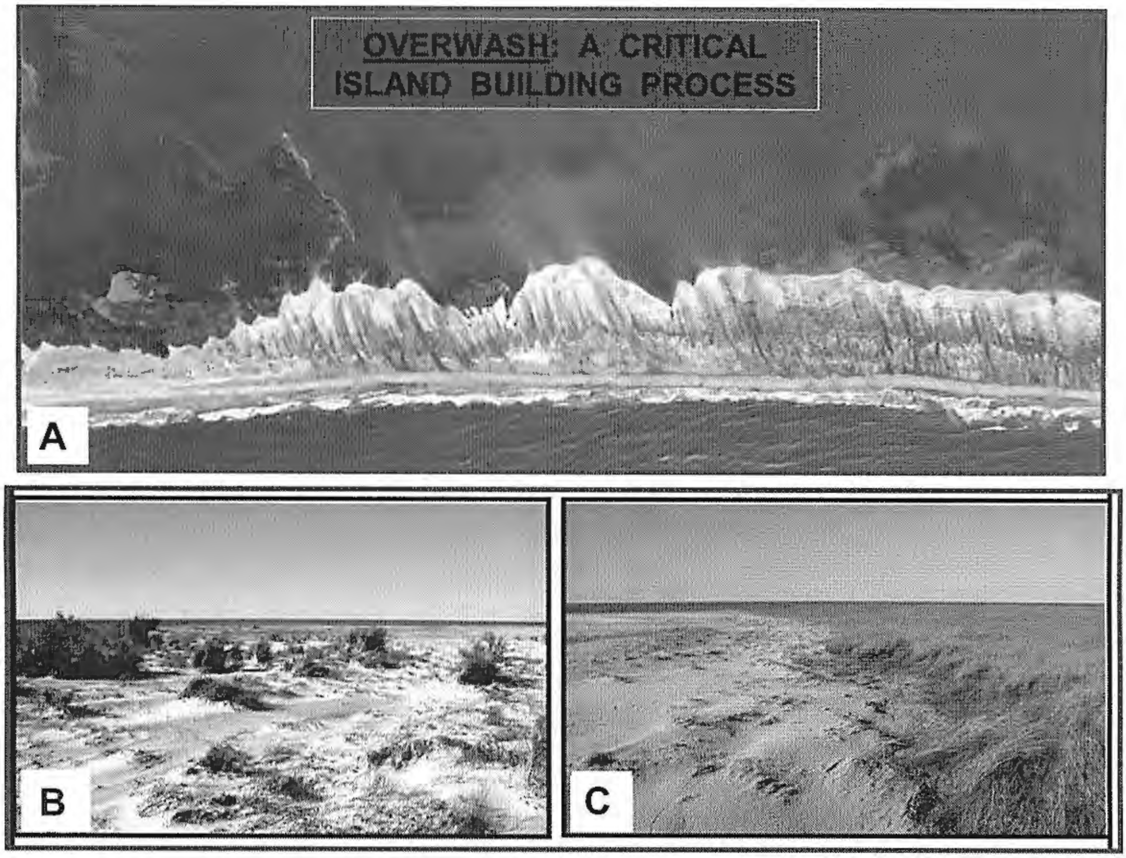


**Figure 2-9. Extensive overwash fans resulting from Hurricane Isabel (Sept. 18, 2003) buried much of the barrier island and deposited sand as sand shoals in the estuaries behind the barrier on North Core Banks with > 1 meter of sand on this 2003 N.O.A.A. aerial photograph (Panel A). The two ground photographs show overwash burying the scrub-shrub zone (Panel B) and the back-barrier marsh platform (Panel C) with up to 1 meter of new sediment. Photographs are by S. Riggs.**

## Humans and Barrier-Dune Ridges

Starting in the late 1930s, North Carolina began a program of building barrier dune ridges along the ocean shoreline from the Virginia line south to Ocracoke Inlet (Figure 2-10A and B). Barrier-dune ridge construction became the dominant policy for protecting N.C. Hwy. 12 after it was paved road down the Outer Banks in the late 1950s and early 1960s. However, barrier-dune ridges, which act as a temporary fort wall to keep the ocean out, are totally out of equilibrium on the Outer Banks barrier islands and extremely vulnerable to ongoing coastal erosion (Figure 2-10C and D). As soon as the dune ridges are constructed, they are attacked by ocean storm waves, become severely scarped, and are quickly breached (Figure 2-11). If the barrier-dune ridges that are protecting N.C. Hwy. 12 are breached, the overwash through the breach will either bury the highway with sand or take the highway out completely (Figure 2-12).

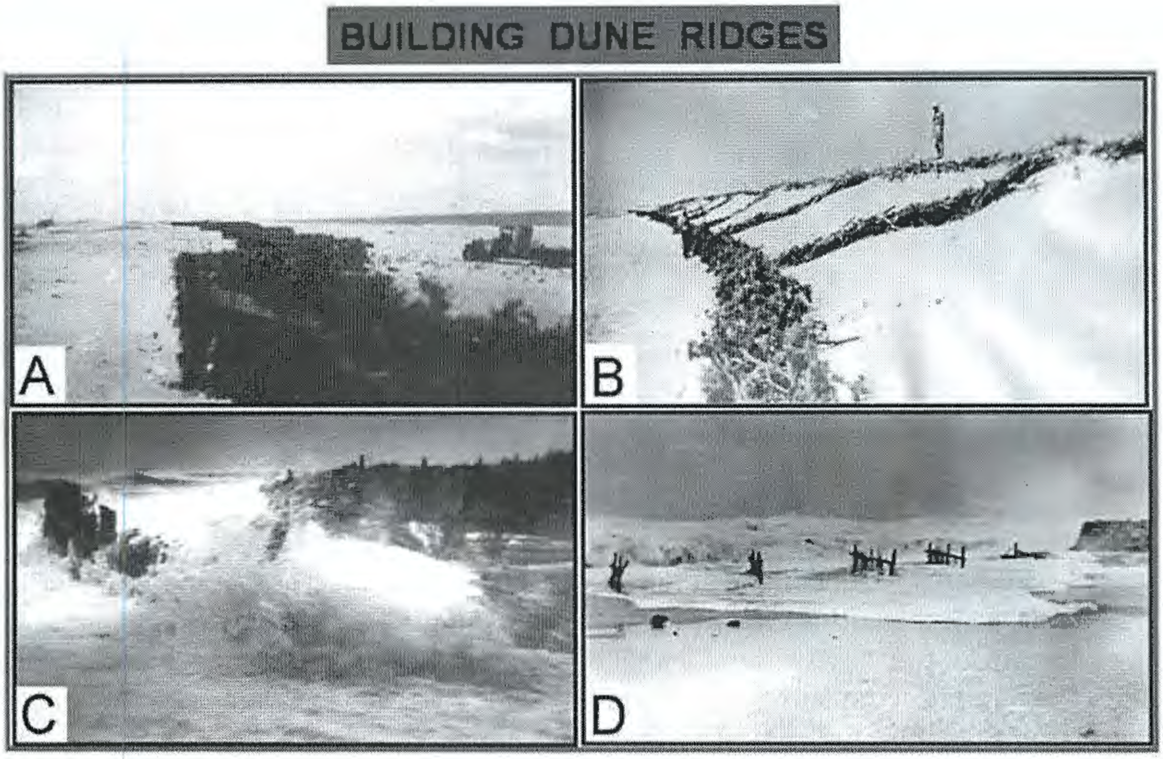
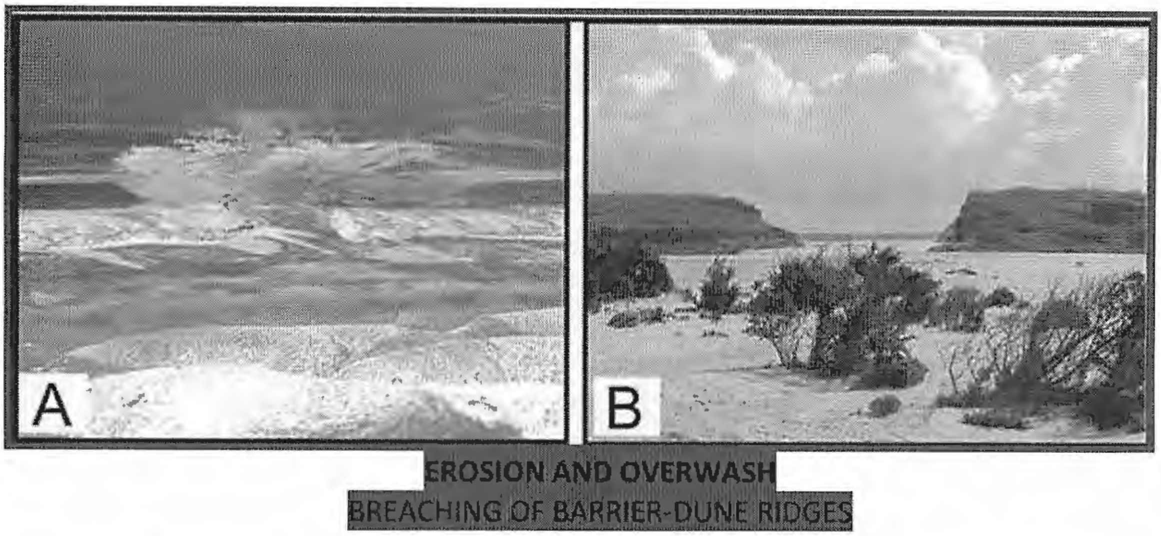


Figure 2-10. A series of historical photographs by Cape Hatteras National Seashore personnel show the various steps in construction of barrier-dune ridges that began in the late 1930s along the northern Outer Banks. Panel A. Shrub fencing was utilized to trap sand on the low overwash dominated barrier beaches that were characterized by an equilibrium profile. Panel B. Additional shrub groins and revetments were utilized to stabilize the dune ridge once the shrub fencing had trapped a ridge of sand. Panel C. Because the barrier-dune ridges were not in equilibrium with the beach dynamics, the subsequent storms readily breached the ridges. Panel D. The storm eroded out much of the barrier-dune ridge and returned the beach back to its preferred profile of equilibrium. The dune ridge remnants that survived had been severely eroded and were left with vertically scarped front sides.



**<u>Figure 2-11</u>. <u>Panel A</u>. An oblique aerial photograph shows a scarped barrier-dune ridge that finally breached during Hurricane Isabel and deposited a small overwash fan across the back side of the barrier island. <u>Panel B</u>. A ground view of the same overwash breach shows the buried scrub-shrub zone buried beneath ~1/2 meter of overwash sand. Photographs are by Cape Hatteras National Seashore personnel.**

After the storm takes out N.C. Hwy. 12, the process of rebuilding the barrier-dune ridges and the road starts all over again (Figure 2-13), now with even higher dune ridges or, in some cases, even double dune ridges. But the barrier-dune ridge is still out of equilibrium and often before construction is completed, erosion has already steeply scarped the dune (Figure 2-13C). If shoreline erosion has encroached too close to N.C. Hwy. 12 and there is enough room, the road will be moved back once again (Figure 2-2). In many places, however, such as at the Sea-View site (Figure 2-1), the island is already too narrow and there is no longer upland space upon which to move the road.

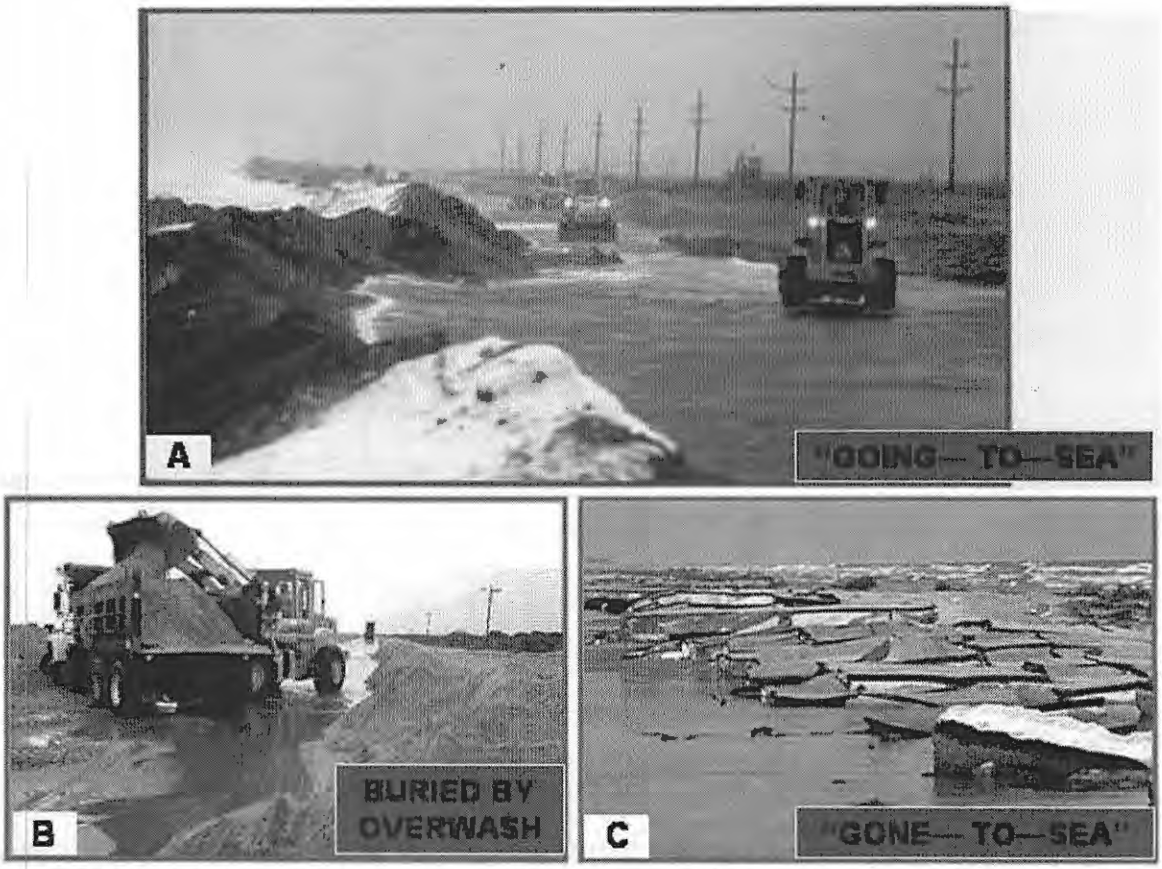


Figure 2-12. N.C. Hwy. 12 "going-to-sea" as the storm tide washes over the road during a typical nor'easter. In some storms the highway is just buried in overwash sand that is cleared off the road and put back into a barrier-dune ridge. Other storms physically destroy the road as it finds itself in the surf zone. Photograph A is by O.H. Pilkey, B is by S. Riggs, and C is by Cape Hatteras National Seashore personnel.

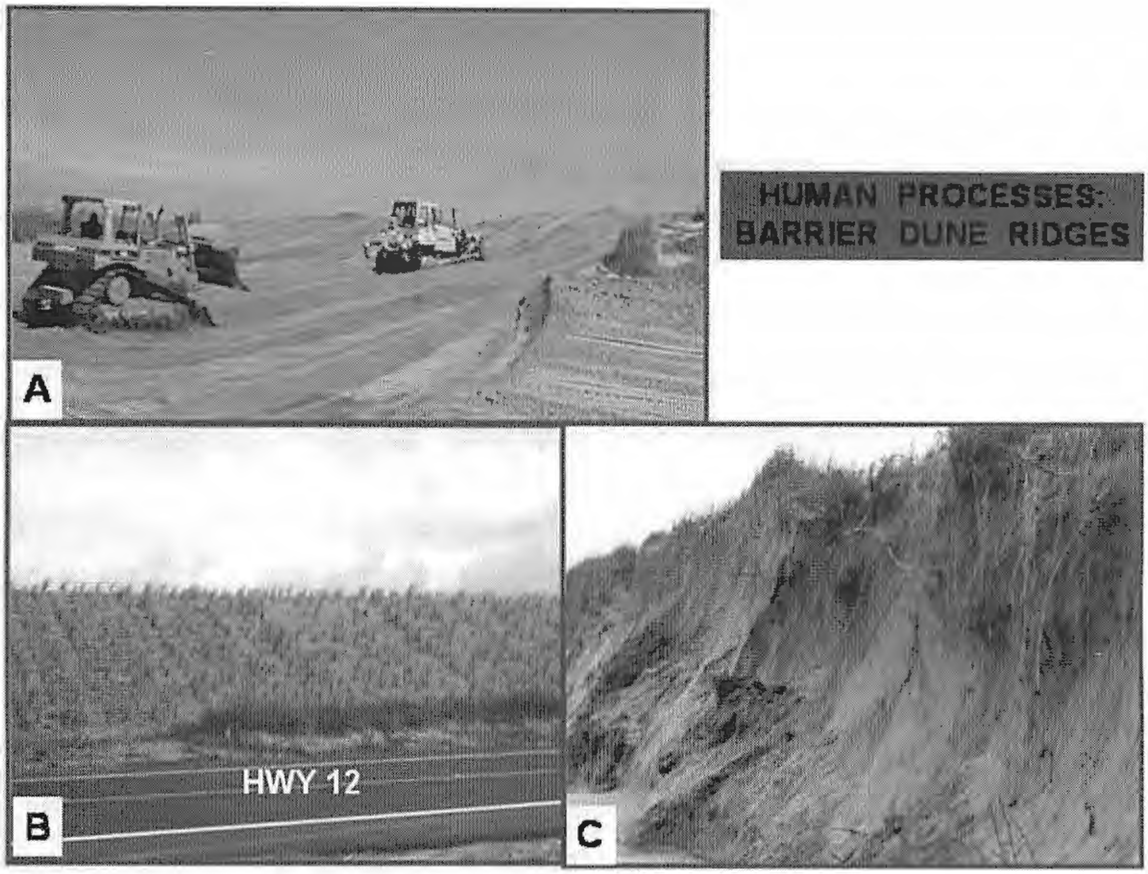


**Figure 2-13. Panel A. Photo shows N.C. Department of Transportation bulldozers rebuilding a new barrier dune ridge after Hurricane Isabel in 2003. Panel B. Looking east at the newly constructed and vegetated barrier-dune ridge built to protect the post-Hurricane Dennis relocated N.C. Hwy. 12 (Figure 2-2B). Panel C. Photograph of the ocean side of a recently constructed barrier dune ridge that shows severe erosion and scarping of the barrier dune ridge that is totally out of equilibrium with the ocean dynamics. Photographs are by S. Riggs.**

The policy of building barrier dune ridges down the Outer Banks since the late 1930s, and with particular regularity since the early 1960s in an effort to protect N.C. Hwy. 12, has had a significant long-term impact upon the health of the overwash dominated barrier islands. The barrier dune ridges have prevented natural island building by inhibiting the critical processes of overwash and inlet dynamics. Three general consequences have occurred in direct response for maintaining this policy through time.

1. The ocean shoreline continues to erode.
2. The barrier-dune ridge is out of equilibrium with ocean dynamics and ultimately erodes causing severe damage to N.C. Hwy. 12 and other ocean-front structures.
3. Little sand moves to the back-barrier habitats, and estuarine shoreline erosion increases—resulting in overall island narrowing.

Thus, human development practices (i.e., building barrier-dune ridges, roads, and extensive walls of ocean-front buildings) cause major changes in the natural processes associated with overwash and inlet dynamics. The inability of overwash or inlet sands to reach the back-barrier habitats and build both barrier island elevation and width results in increased erosion along the estuarine shoreline (Riggs and Ames, 2003). Pamlico Sound is a major inland sea with a significant fetch that can readily create storm surges up to 5 to 10 feet above mean sea level. Such storms are highly erosive to the sound-side shorelines, particularly if these shorelines are not continuously maintained with new overwash sands and inlet flood-tide delta shoals.

The lack of cross-island sand delivery results in the back-barrier estuarine shoreline shifting from a shoreline dominated by constructive processes (i.e., marsh building) to one dominated by destructive processes as the marsh begins to recede around the edge through shoreline erosion as seen in Figure 2-14 (Riggs and Ames, 2003). Human intervention does not stop the ongoing recession of the ocean shoreline—as indicated by the four westward relocations of the highway (Figure 2-2). Thus, the associated barrier-dune ridges have neither protected the highway nor allowed the natural processes of overwash to build and maintain the back barrier system, which is now in a destructive or erosional mode. The net result is an overall increase in island narrowing, rather than island building. Against the backdrop of barrier island evolution and rising sea level, this policy is like giving these weak barrier island segments a long-term death sentence. This is dramatically demonstrated by the ongoing collapse of many segments of N.C. Hwy. 12 and the prediction that large island segments will totally disappear within the next few decades (see *Part One, Lesson Eight*).

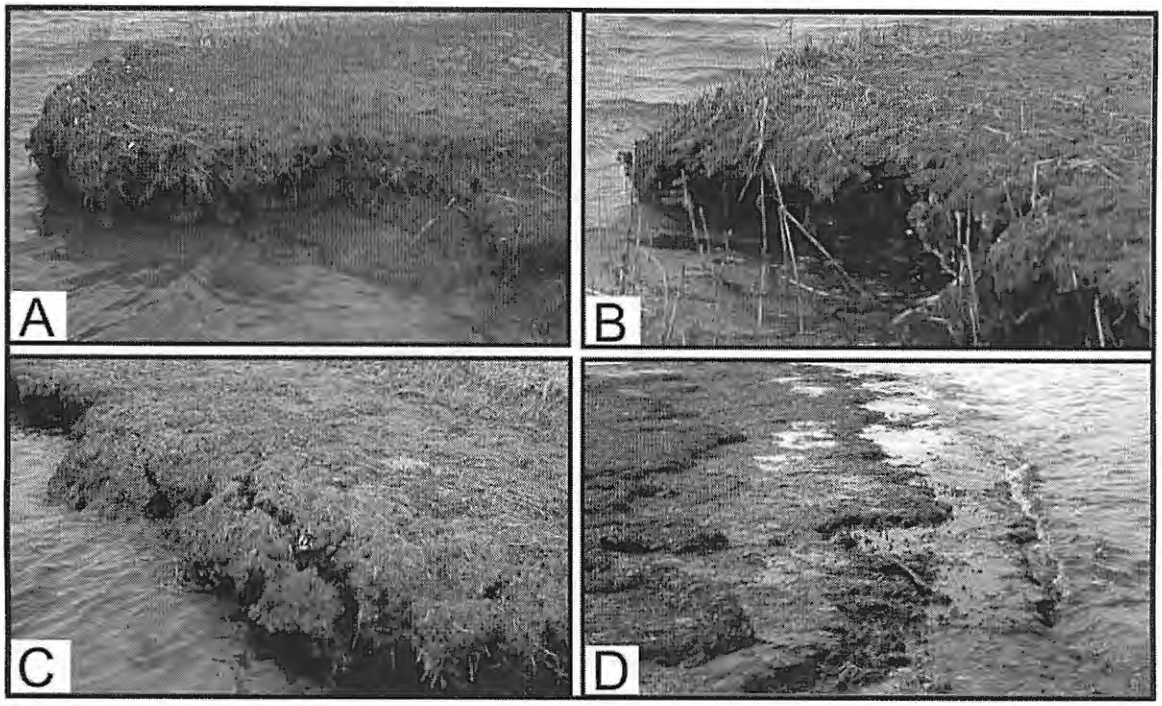


**Figure 2-14. Panel A. Photograph of the outer marsh platform edge shows a vertically scarped peat shoreline that is eroding at an average annual rate of -2.6 feet/year with maximum rates locally up to -18.6 feet/year. Notice that wave energy has largely stripped off the marsh grass from the outer portion of the platform. Panel B. Photograph of the marsh platform shoreline shows the process of erosion by undercutting the upper root-bound zone causing the marsh edge to start sloping seaward. Panel C. The outer block of peat has recently cracked and will ultimately break off of the platform and slowly disintegrate in response to continued wave and biological activity. Panel D. If wave energy is high enough and the marsh peat consists of alternating layers of sand (stormy periods) and peat growth (non-stormy periods), the marsh can erode by stripping off successive peat layers from the upper surface as shown in this photo. Photographs are by S. Riggs.**

## Summary

The Avon-Buxton site provides an excellent example of coastal processes and conflicts that arise when those processes complicate the lives of humans. As this unit shows, understanding the natural processes is important in making wise decisions about use of this unique island environment. It is absolutely certain that we cannot control the work of wind and waves, but we can adjust our human activities to accommodate the inevitable changes that result.

Although the effects of storms and sea-level rise are particularly dramatic on the Outer Banks, natural processes produce changes in every environment. If you are knowledgeable about those processes in your own community, you are in a better position to make sound decisions that are in harmony with those conflicts rather than decisions made in ignorance and that result in economic and human disaster.

## Student Learning Cycle

### Lesson 1: Using Coastal Evidence to Make Management Decisions

**Engage:**

Show students a slide of Figure 2-2. Ask these questions:

1. In what direction has N.C. Hwy. 12 been moved in the period prior to 1999 (Figure 2-2)? Explain why.

2. What effects do you think the movement of the highway has as the ocean shoreline continues to erode?

3. Recall from *Part 1*: What are the consequences of continuous rebuilding of human-made barrier-dune ridges along the ocean beach as shown in Figures 2-2 and 2-4? (Remember: barrier-dune ridges are walls of sand constructed by bulldozers to serve as barriers between the ocean and coastal development such as roads, houses, and business as in Figure 2-4.) .

**Explore:**

Show students a slide of Figure 2-7. Briefly explain (using teacher background information) the formation of the inlet and the subsequent closing.

Although the decision was made to close Isabel Inlet (Figure 2-7) with sand and rebuild N.C. Hwy. 12 immediately, some North Carolinians opposed that action. In completing the following assignments, assume that the inlet has just formed and that you are in a position to influence the decision about either filling it or choosing another alternative to maintain a viable economic infrastructure.

Explain to students that they will read articles related to closing of the inlet and will address the pros and cons of filling Isabel Inlet and re-establishing N.C. Hwy. 12 immediately after Hurricane Isabel. Form three groups of students as described below.

Class Assignment:

A. Read the enclosed newspaper articles printed in this lesson or other relevant articles that your teacher has collected.

B. Work with your group as directed by your teacher.

C. One group will argue for closure of the inlet and include the following citizen assignments:

- A resident of Hatteras Village with two children who attend school in Buxton on the other side of the inlet
- A local politician who represents the residents of Dare County
- A representative of the Dare County Tourism Bureau
- The owner of a motel in Hatteras Village used by fishermen

D. The second group will argue for leaving the inlet as it is and explore other means to transport people from one side to the other and include the following citizen assignments:

- A coastal geologist
- An environmentalist
- A wildlife manager
- A state representative who is on the budget committee

E. A committee (group 3) who will hear the arguments from both sides and make a recommendation to the Governor (with as many members as you choose). While the advocate groups are working, the committee will read all of the articles and make notes of relevant points that they will use to help make a decision.

F. Groups 1 and 2 may have extra members who will serve as "research assistants" to help the committee find additional information to support their position. You may use sources other than the included articles to support your case.

G. Allow each side to present its points for a set time limit and then have one person summarize for each side.

H. Committee #3 will discuss the pros and cons and prepare a written report to submit to the Governor outlining their recommendation and the reasons for their decision. Although this exercise is a simulation, it will prepare you to advocate in the future for a particular course of action, and it will give you experience in considering all kinds of evidence and a wide range of opinions before you make decisions.

## Reading #1: Basnight Lobbies for Coast (This article is reprinted with permission of *The News & Observer* of Raleigh, North Carolina, 2003)

By Jerry Allegood, Staff Writer

COINJOCK --As Marc Basnight approaches the high-rise bridge over the Atlantic Intracoastal Waterway in Currituck County, he reaches for his cell phone. "It'll be better reception up here," he explains as his Ford Explorer rises over the lowlands and backwaters that spread out for miles. He checks with his office in Raleigh, returns a call and snaps the phone back in its holder before heading to meet local officials. A call from Basnight..... can get things done.

After 19 years in the [state] Senate, he knows government terrain like he knows the flatlands of Eastern North Carolina where he was born and raised. Officially, he's leader of the Senate; unofficially, he's one of the state's most powerful politicians. The past few days, Basnight, 56, has been in fine form, unabashedly using his political and persuasive powers to speed government aid to northeastern North Carolina after its mugging by Hurricane Isabel. He's not reluctant to call Gov. Mike Easley or top officials of the Federal Emergency Management Agency.

His lobbying has helped focus state and federal assistance to repair N.C. Hwy. 12, the only highway down the Outer Banks, after it was battered by ocean overwash and severed on Hatteras Island. A fleet of yellow state Department of Transportation road graders and trucks hauled sand off the highway soon after the winds died down last week. He had his assistants working with federal agencies on a way to quickly fill in the new inlet near Hatteras Village.

Basnight said he gets personally involved because the beaches and the barrier islands are crucial to the local economy. Not only do tourists spend money, he said, but local residents build, paint, clean and staff beach houses and businesses. "This is a common man's beach," he says of the Outer Banks. "It's not a black-tie beach."

Over the years, Basnight has worn out a few vehicles traveling around to keep tabs on his domain. After Hurricane Dennis washed out a section of N.C. Hwy. 12 north of Buxton in 1999, Basnight drove his Chevy Suburban over the washout to reach the village. He was there before the NC National Guard came in with Humvees. *Business North Carolina* magazine dubbed him "Boss Basnight." The walls of his restaurant, the Lone Cedar Cafe, are adorned with photos of him posing with the powerful and famous: Billy Graham, Dean Smith, Andy Griffith, President Bush and former President Clinton. Still, Basnight is disarmingly folksy at home in the northeastern corner of the state.

During a tour of hurricane-damaged areas Thursday, he started the day by walking through Henry's Beef and Seafood Restaurant in Kill Devil Hills, shaking hands and asking people how they fared in the storm. "Is he a senator?" asked Richard Boyd of Dante, Va. Boyd didn't know the guy in casual shirt, white jeans and sneakers, but he gladly told him about the damage to his beach house in Kill Devil Hills. Others knew.

Restaurant operator Linda Ezzell snapped a photo of Basnight with Kitty Hawk Mayor Bill Harris and David Stick, a local historian and writer. On the way out of Dare County, Basnight noticed floodwater still standing around homes and businesses. He got on the phone to an aide in his office. "Get in touch with DOT," he said. "Tell them please get more pumps in here."

In Elizabeth City, Basnight met with local officials. He put his chief of staff, Rolf Blizzard, on a speaker phone to take down questions. Pasquotank County Manager Randy Keaton was upset with a FEMA decision not to pay for removing storm debris in subdivisions where roads are not part of state or local road systems. "If they (FEMA) cleaned up the Triangle during the ice storm, they sure better clean up this area from this storm," he said. Basnight agreed to look into the policy, which could add millions to the state and local bill for the Isabel cleanup.

In Colerain, a small Bertie County town on the Chowan River, he toured what was left of the Perry-Wynns fish company after it was hit by a wall of water pushed up the river. Nine of 11 buildings on the shoreline were destroyed, and the other two were left in shambles. A week after the hurricane, the shoreline was still littered with a massive pile of barrels that were used for salting fish. The 50-year-old company, which had about 10 employees, was once a major processor for herring caught in the Chowan and nearby waters but in recent years mainly packed herring, jumping mullet and mackerel caught elsewhere. "It's a family business," said co-owner and manager Lee Wynns. "We've just got to sit down and see what everyone feels about it. You derned well know I'd like to put it back."

On the way back to his Manteo home, Basnight said the nine-hour tour through nine counties had helped him better understand what the state needs to do to weather future storms. "The decisions we make will not affect just what it looks like," he said, "but how people feel about it."

## **Reading #2: World Environment News (Reuters News Service 2003), National Geographic News (November 10, 2003).**

According to the *World Environment News* (Internet), the repair work on Isabel Inlet took two months and cost $7 million. According to the authors, the expenditure "is evidence of the politically driven haste with which officials rushed to restore a road that many old-timers here believe will wash away again when the next big hurricane hits . . .". The constant cycle of storms and road repair (or in this case inlet filling) has prompted some officials to offer an alternative. Dare County Commissioner Renee Cahoon explained that the response to Isabel was prompted primarily by the need for people to return to their homes. Considering the cost and the fact that the problem of storms is a constant, Commission Cahoon said that a bridge is needed to provide access along this span—without having to rely on a constantly threatened roadway.

Government statistics show that large numbers of U.S. residents continue to move to coastal areas along the Pacific, Atlantic, and the Gulf. From 1970 to 2000, Dare County's population grew 328% compared to 58% for the state as a whole.

Orrin Pilkey, a Duke University geology professor, has strong feelings about issues facing the islands. According to Pilkey, "Very powerful and very wealthy people live along the beaches. The politically correct thing to do is rush in and help these people who have suffered from an act of God." Residents who lost property have a different perspective. As the owners of the Sea Gull Motel in Hatteras viewed the destruction to their business that had been in the family for 50 years, they were not sure that they were "up to building another motel."

Stan Riggs, a coastal geologist at East Carolina University, says that there is ample evidence that more inlets will form along the islands of the Outer Banks, but that government officials have "little patience to listen to his evidence." According to Riggs, "we were told by government officials after the storm they did not need any geological input. All decisions were being made in Raleigh and Washington."

Riggs says that barrier islands are naturally migrating inland and that storms are essential to the process. The storms transport huge amounts of sand from the ocean side to the sound side of the islands. Once the sand is deposited, vegetation colonizes and stabilizes the sand. Riggs says, "We think we can put roads out there like we normally build roads in upland regions, and the minute we put something out there we want to protect it. All of a sudden we are at war with the ocean."

Riggs goes on to say that the estuarine side of the island has been deprived of sand because of the actions to maintain the road and the artificial dune line. The process in turn weakens the islands and makes them more prone to form inlets as storms hit.

An official of the N.C. Department of Transportation conceded that the efforts of DOT "can't ultimately beat nature." Although Isabel Inlet called for immediate action, a task force is considering a long-term solution, including the possibility of a causeway along the sound side of the island. Geologist Pilkey agrees that this kind of approach holds great promise.

## Explain:

Step G (presentation of arguments) serves as the "explain" step of the learning cycle. The teacher's role is to facilitate the exploration process to be sure students are collecting appropriate information to support their side of the debate. In addition, the teacher should discuss at this point the importance of considering all the evidence when making important decisions.

## Elaborate:

Have students brainstorm issues that occur in local communities, the state, and the nation that require responsible citizens to gather evidence before making decisions.
Examples: zoning decisions, construction regulations, approval of new drugs or new medical procedures, sources of water for human use, etc. Ask students to discuss the kinds of evidence they would want to consider in dealing with selected issues.

## Evaluate:

The elaboration step serves as an evaluation of this lesson.

## Lesson 2: Making a Cross-Island Topographic Profile

Background Information for Teacher:
The Avon-Buxton Sea-View team constructed a topographic profile across the island along a line from the sound to the ocean marked on Figure 2-1. Their profile shows the vertical elevation (ups and downs) of the island with the ocean side on the right—or east side of the island—and the sounds on the left. To produce a profile that shows the island topography, you need to plot the elevation against the horizontal distance measurements on a graph. Studying a profile of a site provides you a 2-D snapshot of that particular site. Changes in the topographic profile over time provides clues to the dynamics of the site, and comparing profiles from different sites on the islands helps to determine the differences in the type and intensity of processes that shape the islands. The procedures for constructing a barrier island profile may also be used to produce a profile of any site—even your schoolyard.

In this exercise, your students will use the data that the Sea-View team collected to construct a profile on graph paper. In a later assignment, they will collect their own data in your school yard or at some other site. A single profile provides a visual representation of the "ups and downs" or topography of the beach or any other site you choose. Multiple profiles at a site would provide data that would enable construction of a topographic map.

### Engage:
Show students a slide of Figure 2-1. Explain that the Sea-View students worked their way all the way across the island, measuring the height of the island at intervals to create a profile. Ask the students to use the scale on the slide to estimate the width of the island at the Sea-View site. State: You will be recreating a profile of the island, using the data gathered by the Sea-View students.

### Explore:
Have students work in groups to complete the activity described below.

- Make copies of graph paper at the end of this module.
- Discuss with your class how the selection of a scale affects the relationship of the graphed profile to the actual topography or "ups and downs" of the island from sound to ocean.

Instructions for students:

1. Using a piece of graph paper, determine the horizontal and vertical scales that will allow graphing the data on the horizontal and vertical axes respectively. Label the horizontal and vertical axes in meters. You may choose to tape several pieces of graph paper end-to-end to stretch out your profile diagram.

2. Correctly label the horizontal and vertical axis on each graph sheet. Locate the sound side on the left and progress across the island to the ocean side on the right.

3. The object of the exercise was to measure the height of the island at measured distances along a straight, horizontal line between the sound and ocean. Notice that the change in elevation is added to or subtracted from the previous elevation at each measurement point. As you plot the data, you will see that each measurement is compared to the previous one; higher elevation means you add and lower elevation means you subtract.

4. Plot the data gathered by the Sea-View team at the Avon-Buxton research site (Table 2-1).

5. Label the following features: sound, marsh platform, N.C. Hwy. 12, barrier-dune ridge, erosional scarp, ocean shoreline. Refer to a slide of Figure 2-2 to see some of the features that are labeled on your profile.

Table 2-1. Sea-View data collected using a "stick-and-string" method for the cross-island topographic profile at the Avon-Buxton site. The data are from the sound to the ocean with distinguishing features and plants found at specific locations along the profile. See Figure 2-1 and Figure 2-2 for the profile location.

| Distance (m) from Sound Shore | Elevation (m) | Distinguishing Features | Plant Community* |
|---|---|---|---|
| 0 | 0 | Shoreline | Marsh grass |
| 5 | 0.2 | Wrack line* | Marsh grass |
| 10 | 0.3 | Wrack line* | Marsh grass |
| 14 | 0.4 | | Marsh grass |
| 24 | 0.6 | | Marsh grass |
| 28 | 0.8 | | Marsh grass |
| 30 | 1 | | Transition zone |
| 35 | 1.2 | | Transition zone |
| 40 | 1.7 | Top of overwash fan | Scrub-shrub |
| 46 | 1.8 | | Scrub-shrub |
| 50 | 1.6 | | Scrub-shrub |
| 55 | 1.6 | Sand road beneath power line | Overwash plain |
| 60 | 1.6 | | Overwash plain |
| 67 | 1.8 | NC Highway 12—west side | |
| 80 | 1.8 | NC Highway 12—east side | |
| 85 | 1.9 | | Overwash plain |
| 87 | 2 | | Overwash plain |
| 90 | 2.5 | Beginning 1st barrier dune ridge | Beach grass |
| 95 | 3.2 | | Beach grass |
| 100 | 3.5 | | Beach grass |
| 105 | 3.8 | | Beach grass |
| 110 | 3.9 | | Beach grass |
| 115 | 4.1 | | Beach grass |
| 120 | 4.3 | | Beach grass |
| 125 | 4 | | Beach grass |
| 128 | 3.5 | | Beach grass |
| 133 | 4 | Beginning 2nd barrier dune ridge | Beach grass |
| 137 | 5 | | Beach grass |
| 140 | 6.1 | | Beach grass |
| 147 | 7 | | Beach grass |
| 150 | 7.2 | | Beach grass |
| 153 | 7 | Top of erosional scarp in dune ridge | |
| 160 | 4 | Storm beach | |
| 165 | 2.9 | Berm crest | |
| 170 | 2.8 | | |
| 175 | 2.8 | | |
| 180 | 2.8 | | |
| 185 | 2.9 | | |
| 190 | 2.8 | | |
| 195 | 2.6 | | |
| 200 | 2.3 | | |
| 205 | 1.9 | Top of high-tide beach | |
| 210 | 1.4 | | |
| 215 | 0.8 | Top of low-tide beach | |
| 220 | 0 | Bottom of low-tide beach | |

* The plant communities listed in Table 2-1 include the following dominant types of vegetation:

Marsh grass community:
    Black needle rush, salt marsh cordgrass, salt meadow hay
Wrack community:
    Eel grass (dead submerged aquatic grass that gets washed up during storm events)
Transition zone community:
    Marsh elder, cotton bush, wax myrtle, marsh glasswort, sea oxeye
Scrub-shrub community:
    Juniper, youpon, live oak, sweet bay
Overwash plain community:
    Salt meadow hay, prickly pear cactus, sea oxeye, sand spur, Pennywort, broom-straw rush
Beach grass community:
    Sea oats, American beach grass, penneywort, sea elder, sea rocket

**Explain:**

Have groups exhibit their profiles to the whole class. Discuss reasons for differences (perhaps they chose different scales?). Be sure students understand what they are seeing when they see the profiles—a cross section of the island along a line that crosses the island from sound to ocean.

Referring back to the sea-level curves in *Part 1*, note that the long-term rise in sea level for North Carolina is about 1.5 feet per century. How high would sea level need to rise to cover N.C. Hwy. 12 at the Avon-Buxton site? Based upon the ongoing long-term rise in sea level for N.C., how long would that take? Can this much rise in sea level take place on a temporary and short-term basis? If so, how and when does that happen?

If the Sea-View team returned to the Avon-Buxton site at a later date and measured elevations along the same cross island profile, what differences might they anticipate finding—considering that the wind, waves, and humans constantly change the features of the islands?

**Elaborate:**

Find a field guide book for coastal plants in the library/Internet and identify the plants that occur within each of the major communities. Make copies of photographs of the dominant plants to attach to your graph.

**Evaluate:**
Provide the data set below (Table 2-2) from a site on another barrier island off the North Carolina coast. This profile does not cross over the entire island. It just shows a profile of the beach at the site. Have students work individually to plot the points. Check to see if graphs are labeled correctly.

From the appearance of the graph, what can you say about the topography at this site that is different from the Avon-Buxton site?

Table 2-2

| Distance from shore (meters) | Elevation (centimeters) |
|---|---|
| 0 | 0 |
| 3 | 2.0 |
| 6 | 3.0 |
| 9 | 4.5 |
| 12 | 6.4 |
| 15 | 10.8 |
| 18 | 12.1 |
| 21 | 11.5 |
| 24 | 10.9 |
| 27 | 9.9 |
| 30 | 9.4 |
| 33 | 11.9 |
| 36 | 15.6 |
| 39 | 17.0 |
| 42 | 22.0 |
| 45 | 23.5 |
| 48 | 21.8 |
| 51 | 13.5 |
| 54 | 11.0 |
| 57 | 9.5 |

## Lesson 3: Making a Topographic Profile of Your School Yard

The method used by the Sea-View team to create a barrier island profile at Avon-Buxton can be used to map the topography of specific areas around your school yard. Constructing profiles provides valuable experience in gathering, recording, and analyzing data. Once the profiles are constructed, discuss the factors and processes that might have produced the topography that is represented by your data.

### Engage:

If we did a topographic profile across our school yard, how do you think it would look on a piece of graph paper? Would it more closely resemble the Avon-Buxton profile or the other profile you did?

### Explore:

To students: The data you used for your two profiles was gathered through a technique that measured horizontal distance intervals across a line chosen for the profile as well as vertical distances determined at each interval. We will now learn how to use that method to gather our own profile data.

Provide student groups with the following instructions and demonstrate for them how to take the measurements. Give them a little time to practice before they begin gathering data at their assigned site.

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Purpose: To introduce topographic mapping techniques and produce topographic profiles and a topographic map of a part of your campus.

Materials (per group):

-Two pieces of 2" x 2" x 8' wood boards or other similar material
-Ball of heavy string or light rope
-Marker pen
-Measuring tape
-Hanging string level, masonry line level, or sight level
-Graph paper
-Profile data sheet, pencil and eraser

Getting ready:

1. Cut a groove into one of the sticks exactly four feet from the bottom in order to keep the string in place.
2. Using the marker and the measuring tape, place a zero mark at the halfway point on the second stick. Above that measurement, label the centimeters starting from zero to the top of the stick using negative numbers (you will understand why you do this later). Below the four-foot "zero" mark, count down the pole in positive

centimeters.

3. Measure a 3-meter length of string to be tied between the two sticks. One end of the string will be tied into the groove on the first stick, and the other end should be able to slide up and down the second stick. When placed at the "zero" mark, the line should be perfectly level with both sticks placed on a horizontal floor.
4. Demonstrate how to measure change in elevation in class before going outside.

Procedure: Work in groups of four as directed by your teacher—two to hold the sticks upright, one to use the string level, and one to record the data and make observations at each interval.

1. As directed by your teacher, locate your group and equipment a set distance apart from other groups (e.g., every 3 meters). Set the number of measurements to be taken according to the length of the field area and the complexity and amount of relief in the topography to be surveyed. It might help to have all the groups start at a central point and fan out in all directions. If you use this method you will collect data that you can then use to construct a topographic map of your school yard.

2. Place the stick with the groove at the starting position and separate the sticks until the string is taut. Always lead with the marked stick. Slide the string along the second stick until the string is level according to the hanging level. Record the distance on the profile data sheet as 3 meters.

3. The recorder will then write down the number of centimeters the string moved from the zero mark in the column labeled *Change in Elevation*. If the string moved up the stick, then record the measurement as a negative number (as previously marked on the stick). Record as a positive number if the string moved down. If you do not understand why this works, discuss it with your teacher.

4. Each team member will help make observations for the recorder to write down at each interval. Observations should include changes in vegetation, descriptions of changes in rock or sediment type and grain size from the bottom to the top of the hill, cliff, ditch, creek bank, etc.; weathering and erosion evidence; depositional features; etc.

5. Move the first stick from the starting point and place it in the exact spot of the second stick. Repeat step 3 for each subsequent measurement. At each new point, move the string along the pole until it is level. Record the horizontal distance and change in elevation.

6. Add each change in elevation to the previous number and record this in the *Total Elevation* column on the data sheet.

7. When the predetermined number of measurements have been made or the given distance has been covered, your group should create a profile of the assigned area

on graph paper, using the same strategy as in the Avon-Buxton Profile assignment. You do not need to know the actual elevation of the starting point in order to begin; just place the starting point strategically on the graph according to the topography of the land. For example, place the first point somewhere in the middle of the page on the far left if you went uphill and downhill equally. Create a scale that will allow the distances to fit on the page. Finally, label and draw any observations that were made on the profile.

8. If you have access to a U.S. Geological Survey topographic map that covers your site, use the map to first locate your site and then determine the general elevation. Use this number to convert your relative measurements to real elevations and use those to plot your topographic profile. Or if a survey was made of your school grounds for the construction or maintenance of major roads, drainages, or a building, etc., there may be an elevation available on the plans.

## Topographic Profile Data Sheet

Name: ______________________ Date: ______________________

Group Members: ______________________ Period: ______________________

Location: ______________________ Topographic Profile No. ______________________

| Station Number | Distance | Change in Elevation | Total Elevation | Observations |
|---|---|---|---|---|
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The elevation of a site, as shown in a profile, should influence decisions about the site use. The next assignment addresses that issue.

**Explain:**

Have students display their graphs to the class and explain how they derived each point. Be sure that their techniques in the field and their recording of data are done correctly. Discuss why there are differences in the graphs—relate the differences to the different sites explored by different groups—and perhaps to different scales used on the graphs.

**Elaborate:**

Have students discuss how the topography of a site influences processes such as erosion, water flow, and sediment run-off into streams. What other factors influence those processes? Take another field trip to your school yard or the site used for the exploration. Look for evidence of the processes discussed above. How does topography play a role? What measures (if any) are being used to mitigate or influence the processes? What measures would you recommend?

**Evaluate:**

Provide the following assignment for students. This problem presents topographic data in a different context, requiring students to transfer the knowledge they have gained in the previous exploration to a new situation.

Scenario: A research vessel crossed the Atlantic Ocean traveling east along 39°N latitude. The ship had instruments that measured both the distance from the eastern shore of North America and the depth of the ocean at specified intervals. Look at the data provided on the data table below (Table 2-3) and think about how you would set up your graph. Clue: Your starting point (0) is where the land and the sea meet (shoreline). Where should you place this point on your graph to show the change in the sea floor across the Atlantic? Which distances should go on the vertical axis and which on the horizontal? Decide on a scale and label the axes appropriately. Plot the points on your graph paper and connect the points. What features on the ocean floor can you identify on your graph?

Table 2-3

| Distance from North America (km) | Depth (m) |
|---|---|
| 0 | 0 |
| 160 | 165 |
| 200 | 1800 |
| 500 | 3500 |
| 800 | 4600 |
| 1050 | 5450 |
| 1450 | 5100 |
| 1800 | 5300 |
| 2000 | 5600 |
| 2300 | 4750 |
| 2400 | 3500 |
| 2600 | 3100 |
| 3000 | 4300 |
| 3200 | 3900 |
| 3450 | 3400 |
| 3550 | 2100 |
| 3699 | 1330 |
| 3700 | 1275 |
| 3950 | 1000 |
| 4000 | 0 |
| 4100 | 1300 |
| 4350 | 3650 |
| 4500 | 5100 |
| 5000 | 5000 |
| 5300 | 4200 |
| 5450 | 1800 |
| 5500 | 920 |
| 5600 | 180 |
| 5650 | 0 |

## Lesson 4: Using Scientific Evidence to Make Community Decisions

Although the circumstances of a narrow barrier island subject to hurricane force winds are not common throughout the country, every community must consider the natural processes at work locally and their consequences for the environment and for humans. If you don't live on an island, you probably have a river or stream near your school or home. The energy carried by moving water can have effects on inland areas that can be as destructive as the effects of storms on the Outer Banks.

### Engage:

Discuss these questions:

1. What are the consequences of using land that lies within flood-prone areas along your river?
2. What kinds of uses might be appropriate for land that periodically floods?

### Explore:

Have students work in groups to complete the assignment below.

1. Read the editorial below (Used with permission of *The Daily Reflector,* Greenville, N.C.)
2. Discuss these questions in your class or in small groups:
    A. After Hurricane Floyd, what position did the Greenville City Council take in regard to development in the flood plain? What was the rationale for that decision? What factors prompted a change in this position in 2004?
    B. What is the position of this editorial?
    C. What relevant factors are not included in this editorial?
    D. If you were on the City Council in Greenville, what position would you take in regard to rezoning the property in the flood zone to allow for construction of apartments? What would be your rationale?

### 4/11/04 EDITORIAL: Trouble Rising — Prosperity Means Little if History Repeats

Six weeks ago, a last-minute, out-of-order change to Greenville's comprehensive plan set the stage for land at the intersection of U.S. 264 and Greenville Boulevard to be rezoned.

The City Council sealed that deal last week by approving a request to build 500 apartments on property covered for days by several feet of floodwater during Hurricane Floyd. The decision is the first practical impact of a policy change allowing dwellings in the floodplain of the Tar River. The rezoning came as no surprise. Yet that makes it no easier to accept. A conscientious, sure-footed City Council has ignored history, embracing public policy that places people in harm's way. And in doing so, set a troubling precedent for growth carrying more weight than public safety. Greenville needs no lessons in what happens when you build in flood-prone areas.

In 1999, flooding from Hurricane Floyd covered 58 percent of the land in Pitt County. Six people lost their lives. Hundreds lost their homes. Hundreds more who were stranded by deadly brown water had to be evacuated at great risk to human life.

That disaster laid bare the facts.

In Greenville, hundreds of apartments for students at East Carolina University had been built in the path of floodwaters. So had a public housing project, a large retirement community and trailer parks. An expensive buyout program relocated many of those people. And in 2000, the City Council agreed that no more residential development should take place in the newly drawn floodplain, a deep and sensible bow to nature's humbling lesson.

Now that course has been reversed. Landowners and developers who pushed the change argued that prohibiting dwellings in the floodplain put too much land north of the Tar River, an area that has not shared proportionately in Greenville's prosperity, out of consideration for development.

Yet prosperity will matter little if history repeats itself. Even if dwellings are built above the high-water mark — as the new ordinance requires them to be — floodwater will surround and strand residents in apartment complexes in the same way it did four years ago. The cost of such policy is obvious, both in public dollars and human lives. On both counts, it is the citizens who will pay.

Soon, the foundations of nice, new apartments will appear at the intersection of U.S. 264 and Greenville Boulevard. As they rise, literally, above the lowland, they should serve as a warning of what can happen when public safety takes a back seat and the desire for growth takes the wheel.

## Explain:

Have students discuss their responses to the questions. What scientific evidence was used to develop the city's comprehensive plan? What other kinds of information were used by the city council in changing the comprehensive plan? How does this situation resemble the one in which Isabel Inlet was filled in very soon after it was created by the hurricane in 2003 (*Part 1,* Lesson 13)? What factors are the same in both cases?

## Elaborate:

Conduct research in your own community to find instances in which land use issues were debated. What were the factors presented by opposing sides? What decision was finally made? What scientific evidence (if any) contributed to the decision? What other kinds of information contributed to the decision?

## Evaluate:

The *Elaborate* stage serves as an appropriate evaluation of students' ability to sort out the evidence used in making community decisions regarding land use—a major aim of this lesson.

## Descriptions of Figures, Part 1:

Cover Figure. The Atlantic Ocean beach at South Nags Head, N. C. during a major nor'easter storm, shows relatively new oceanfront houses that are now "going-to-sea" as the shoreline rapidly recedes at average annual rates up to 7 feet/year (NC DCM, 1998). Photograph is by S. Riggs.

P. 7, Figure 1-1. A satellite image of the Northern Coastal Province of North Carolina extends from Cape Lookout north to the mouth of the Chesapeake Bay in Virginia. The image shows the fresh-water riverine systems, vast network of brackish-water estuaries, and the salt-water oceanic system that is separated by the barrier island sand dam with a few small inlet/outlets that allow interchange with the Atlantic Ocean. Image is courtesy of Earth Sciences and Image Analysis Laboratory, NASA Johnson Space Center. Image STS 095-709-14 (*http://eol.jsc.nasa.gov*).

P. 9, Figure 1-2. This satellite image shows the Sea-View site locations. The image is a joint product of the NASA Landsat Project Occupancy Office, Goddard Space Flight Center, and the U.S. Geological Survey EROS Data Center. Figure is modified from Figure 2-1-3, p. 19 in Riggs and Ames (2003).

P. 12, Figure 1-3. This diagram shows the three geologic provinces of North Carolina.

P. 14, Figure 1-4. This geologic time chart contrasts long range geologic time that reaches 4.6 billion years back to the earth's formation, with the more recent human time frame since European colonization of North Carolina (the last 400 years) and the last decade of the 20th century.

P. 15, Figure 1-5. Aerial and ground photographs show the site of Isabel Inlet that opened on Sept. 18, 2003, in response to Hurricane Isabel. Figure is Figure 8-4-18, p. 141 in Riggs and Ames (2003).

P. 19, Figure 1-6. Generalized sea-level curve for the past 40,000 years and predictions to year 2100 AD. Predictions are based upon IPCC (2001). Figure 6-2-1, p. 62 in Riggs and Ames (2003).

P. 20, Figure 1-7. Tide gauge data from Hampton, Va. and Charleston, S.C., demonstrate the rate of ongoing sea-level rise. The two sets of tide-gauge data are from the U.S. National Oceanographic and Atmospheric Administration (NOAA) National Water Level Observation Network (*www.co-ops.nos.noaa.gov/*). Figure 6-3-2, p. 65 in Riggs and Ames (2003).

P. 24, Figure 1-8. The water cycle is fueled by energy from the sun and aided by the force of gravity. Figure is by J. Evans and is from the U.S. Geological Survey.

P. 28, Figure 1-9. Model of estuarine storm tides in the North Carolina sounds that form in response to different storm events. Wave energy added to both high and low storm tides is the primary process driving estuarine shoreline recession. Figure 5-2-1, p. 57 in Riggs and Ames (2003).

P. 31, Figure 1-10. Map of the three geologic Provinces (outlined in black) and drainage basins (outlined in red). The river basins underlain by green color and with the blue drainages drawn in, flow to the Atlantic Ocean and produce the vast northeastern North Carolina coastal system. Figure 2-1-1, p. 17 in Riggs and Ames (2003).

P. 32, Figure 1-11. Location map shows major towns and coastal features for the North Carolina coastal system. Figure 2-1-2, p. 18 in Riggs and Ames (2003).

P. 34, Figure 1-12. Generalized geologic map of the North Carolina Coastal Plain shows the two coastal provinces and four geomorphic compartments of the coastal system. Geologic outcrop patterns are summarized from the Geologic Map of North Carolina (NCGS, 1985). Figure 2-2-1, p. 21 in Riggs and Ames (2003).

P. 39, Figure 1-13. Schematic cross-sectional diagrams show a simple overwash (Panel A) and complex barrier islands (Panel B) and the associated back-barrier estuarine shorelines. Figure 4-5-1, p. 50 in Riggs and Ames 2003.

P. 40, Figure 1-14. Pea Island aerial photographs show a segment of simple overwash barrier island just north of Rodanthe. The bottom panel is a 1998 aerial photograph of Pea Island with a box indicating the area in the NOAA 2003 post-Hurricane Isabel aerial photograph in the upper panel.

P. 41, Figure 1-15. Panel A. The 1943 aerial photograph of Drum Inlet separates North and South Core Banks with extensive sand shoals associated with the tidal deltas. Panel B. This is a 1992 oblique aerial photograph of New Inlet flood-tide delta.

P. 42, Figure 1-16. A 1982 infrared aerial photograph of Kitty Hawk shows the extensive sequence of beach ridges that constitute Kitty Hawk Woods. This is an example of a complex barrier island. Figure 4-5-3, Panel A, p. 52 in Riggs and Ames (2003).

P. 49, Figure 1-17. This figure shows the point of intersection between the sloping land surface and the horizontal water surface. The intersection of these two planes forms a shoreline that will move as water level changes in response to either an increase or decrease in water volume or changes in the water level due to astronomical tides, wind tides, and storm surges.

P. 50, Figure 1-18. The shore zone consists of a series of many shorelines that move up and down continuously on short-term time scales. Each debris line in this photo series represents an individual shoreline that was formed by wave energy, as the falling water level stopped for brief periods at each level. Photographs are by S. Riggs.

P. 52, Figure 1-19. Panel A. The shoreline on a steep granite rock wall that drops into deep water produces a rocky shoreline with no beach because there is neither a shallow slope upon which a beach could accumulate nor sediments available to build a beach. Panels B and C. Adjacent to the rocky headlands, erosion of softer material produces coves with shallow eroded terraces or platforms that accumulate the eroded sediment and form strandplain beaches. Photographs are by S. Riggs.

P. 56, Figure 1-20. Sand beaches on North Carolina's barrier islands are composed mainly of quartz sand with varying amounts of abraded shell material and local areas with concentrations of black heavy mineral sand and river gravel. Photographs are by S. Riggs.

P. 60, Figure 1-21. Post-Hurricane Isabel photos of NE portion of Ocracoke Island that destroyed about 6 miles of N.C. Hwy. 12 and nourished the back-barrier marsh platforms. Photographs A and B are by Cape Hatteras National Seashore personnel. Photographs C through F are by S. Riggs.

P. 62, Figure 1-22. Two aerial photographs of New Inlet on Pea Island show the open and active inlet in 1932 and the closed inlet in 1998 long after it closed naturally in 1945.

P. 65, Figure 1-23. Photograph of a typical shoreline transition zone from the marsh grasses at the edge of the shoreline through shrub-scrub—such as wax myrtle and pond pine—to the upland pines and hardwood trees in the background. Photograph is by S. Riggs.

P. 66, Figure 1-24. Panel A. A highly irregular and eroding marsh platform shoreline occurs at Wades Point in the Pamlico River, Beaufort County. Nags Head Woods has similar steeply scarped and undercut platform marshes. Figure 8-4-1 Panel F, p. 124 in Riggs and Ames (2003). Panel B. Wave action during low tide levels erodes the soft peat layer underlying the tough root-bound modern marsh surface to produce this severely undercut peat block. Figure 8-2-16, Panel D, p. 96 in Riggs and Ames, 2003.

P. 68, Figure 1-25. Schematic model of a sediment-bank shoreline shows the following geomorphic features. 1) A wave-cut scarp and wave-cut platform have been eroded into older sediment units with a strandplain beach perched on the platform. 2) Different water levels and wave sizes that do the work of shoreline erosion, beach building, and beach maintenance. 3) The process of eroding and undercutting the bank top during high storm tides and subsequent slumping and reworking of slump blocks to produce the beach sediments. Figure 4-2-1, p. 38 in Riggs and Ames (2003).

P. 69, Figure 1-26. A high sediment-bank shoreline in Nags Head Woods is being severely eroded by the wave energy along the eastern end of Albemarle Sound. However, erosion is not occurring during the low-energy conditions shown in this photo. Rather, bank erosion occurs during storm conditions when the water level oversteps the beach and directly intersects the sediment-bank. Notice the extensive strandplain beach that is derived from the erosion of the wave-cut scarp comprised of a sand sediment-bank. This Figure is on p. 24 in Riggs and Ames (2003).

P. 70, Figure 1-27. Low sediment-bank shorelines. Panel A. This photograph shows a shoreline along the estuary shoreline at Jockey's Ridge State Park. Figure 8-2-11 Panel E, p. 91 in Riggs and Ames (2003). Panel B A low sediment-bank (in the foreground) and platform marsh (in the background) are actively eroding along the Nags Head Woods estuarine shoreline at the eastern end of Albemarle Sound. Figure is on p. 68 in Riggs and Ames (2003).

P. 75, Figure 1-28. Post-Hurricane Isabel (2003) photographs show the damage in Hatteras Village and the newly opened and quickly closed Isabel Inlet. Photographs are by S. Riggs.

P. 76, Figure 1-29. Shoreline changes on Ocracoke Island are shown for a time period spanning 132 years (1866—1998).

P. 77, Figure 1-30. Two photographs of an eroding estuarine sediment-bank shoreline along the western side of the Chowan River. Figures are the front and back cover of Riggs and Ames (2003).

P. 79, Figure 1-31. This map of historic shorelines reflects a fairly constant rate of shoreline recession for the 113 years from 1852 to 1965 in the area from Buxton to Cape Hatteras. Figure is from Fisher (1967), who modified it from the US ACE (1963). Figure 6-3-1, p. 64 in Riggs and Ames (2003).

P. 80, Figure 1-32. Panels A and B. Photographs of the extensive effort to protect the Cape Hatteras Lighthouse from the encroaching Atlantic Ocean with massive hardened structures. Photographs are by S. Riggs.

P. 81, Figure 1-33 Cape Hatteras Lighthouse is being prepared for its move from the old threatened site adjacent to the rapidly eroding shoreline to a new inland site. Photo is by the N.C. Department of Transportation.

P. 82, Figure 1-34. Cape Hatteras Lighthouse is on its slow and deliberate move towards the new inland relocation site. Photo is by the N.C. Department of Transportation.

P. 83, Figure 1-35. A newspaper article documents damage to N.C. Hwy. 12 in Kitty Hawk with nothing more than an abnormally high spring tide. Photograph is by S. Riggs. Article is used with permission of *The Daily Reflector*, Greenville, N.C.

P. 84, Figure 1-36. Hardened structures along the sediment-bank shorelines within the estuarine system were built in a desperate effort to stabilize the rapidly eroding shoreline. All photographs are by S. Riggs.

**Descriptions of Figures, Part 2:**

p. 87, COVER FIGURE. Panel A. N.O.A.A. 2003 post-Hurricane Isabel aerial photograph of Buxton Village and Cape Hatteras National Seashore, just south of the Sea-View site. Panel B. Ground photograph of the remnant barrier-dune ridge (foreground), the overwash deposit, and the overwash sand that was bulldozed back to rebuild the barrier-dune ridge. Photograph is by S. Riggs.

P. 91, Figure 2-1. A 1998 aerial photograph shows the Avon-Buxton barrier island segment with Buxton Village and the extensive system of beach ridges that constitute Buxton Woods. Figure is modified from Figure 8-2-6, p. 86 in Riggs and Ames (2003).

P. 92, Figure 2-2. The Buxton Inlet site is one of the series of N.C. Hwy. 12 DOT "hot spots" where the coastal highway is in serious jeopardy. Panel A. A 1992 oblique aerial photograph shows the 1992 location, as well as two former locations of N.C. Hwy. 12. Panel B. A 1999 aerial photograph shows a new fourth location of N.C. Hwy. 12 in response to a major overwash event associated with Hurricane Dennis in 1999. Figure is Figure 8-2-5, p. 85 in Riggs and Ames (2003).

P. 93, Figure 2-3. A three-panel, time series analysis of georeferenced aerial photographs show the net change in both island location and width between 1852 and 1998 for the Buxton-Avon area.

P. 94, Figure 2-4. Inlets and overwash fans are critical barrier island building processes that are crucial for their short-term health and long-term evolution. Panel A is an oblique aerial photo of the active New Drum Inlet on Core Banks with a major flood-tide delta formed on the backside of the barrier. Photo is by D. Heron. Panel B is a 1992 oblique aerial photo of New Inlet on Pea Island that closed naturally in 1945 and shows the extensive salt marsh that has grown since the inlet closed. Photo is by S. Riggs. Panels C and D are 2003 ground photos of major overwash fans that took place during Hurricane Isabel. Because of the increased elevation in the marsh, the area will revegatate as shrub-scrub. Photos are by S. Riggs.

P. 96, Figure 2-5. A georeferenced set of aerial photographs shows the location, development, and closure of Buxton Inlet.

P. 97, Figure 2-6. A four-part photo series shows the history of Buxton Inlet which opened in the Ash Wednesday Nor'east storm in March 1962. Panel A. An oblique aerial photograph looking south shows the active inlet with a wooden N.C. Hwy. 12 bridge across it. Photograph is by. Panel B. A nor'east storm in early December 1962 took most of the bridge out. Panel C. An oblique aerial photo looking west was taken on January 29, 1963 and shows the dredge pumping sand from the sound side into the inlet. Panel D. An oblique aerial photo looking north was taken on February 21, 1963 when the inlet was finally closed. Panel A Photograph is by Cape Hatteras National Seashore personnel. Photographs in Panels B, C, and D are from the U.S. Army Corps of Engineers (1963).

P. 99, Figure 2-7. Panel A. A 1998 pre-Hurricane Isabel aerial photograph of a portion of Hatteras Island shows the future location of Isabel Inlet. Photograph is by S. Riggs.

P. 100, Figure 2-8. Panel A. A 2001 photograph of the New Inlet flood-tide delta sand shoals that have evolved into extensive salt marsh after the inlet closed naturally in 1945. Photograph is by S. Riggs. Panel B. This 1932 aerial photograph shows a small, but active, multi-channeled New Inlet with a prominent flood-tide delta. Aerial Photograph is from the U.S. Army Corps of Engineers, Field Research Facility. Panel C. This 1992 oblique aerial photo shows the New Inlet flood-tide delta sand shoals . Photograph is by S. Riggs.

P. 101, Figure 2-9. Extensive overwash fans resulting from Hurricane Isabel (Sept. 18, 2003) buried much of the barrier island on North Core Banks with > 1 meter of sand on this 2003 N.O.A.A. aerial photograph (Panel A).

The two ground photographs show the overwash burying the scrub-shrub zone (Panel B) and the back-barrier marsh platform (Panel C) with up to 1 meter of new sediment. Photographs are by S. Riggs.

P. 102, Figure 2-10. A series of historical photographs by Cape Hatteras National Seashore personnel show the various steps in construction of barrier-dune ridges that began in the late 1930s along the northern Outer Banks.

P. 103, Figure 2-11. Panel A. An oblique aerial photograph shows a scarped barrier-dune ridge that finally breached during Hurricane Isabel and deposited a small overwash fan across the back side of the barrier island. Panel B. A ground view of the same overwash breach shows the buried scrub-shrub zone buried beneath ~1/2 meter of overwash sand. Photographs are by Cape Hatteras National Seashore personnel.

P. 104, Figure 2-12. N.C. Hwy. 12 "going—to—sea" as the storm tide washes over the road during a typical nor'easter. Photograph A is by O.H. Pilkey, B is by S. Riggs, and C is by Cape Hatteras National Seashore personnel.

P. 105, Figure 2-13. Panel A. Photo shows N.C. Department of Transportation bulldozers rebuilding a new barrier dune ridge after Hurricane Isabel in 2003. Photograph is by S. Riggs. Panel B. Looking east at the newly constructed and vegetated barrier-dune ridge built to protect the post-Hurricane Dennis relocated N.C. Hwy. 12 (Figure 2-2B). Figure 8-2-4, Panel F, p. 84 in Riggs and Ames (2003). Panel C. Photograph of the ocean side of a recently constructed barrier dune ridge that shows severe erosion and scarping of the barrier dune ridge that is totally out of equilibrium with the ocean dynamics. Photograph is by S. Riggs.

P. 107, Figure 2-14. Panel A. Photograph of the outer marsh platform edge shows a vertically scarped peat shoreline that is eroding at an average annual rate of -2.6 feet/year with maximum rates locally up to -18.6 feet/year. Panel B. Photograph of the marsh platform shoreline shows the process of erosion by undercutting the upper root-bound zone causing the marsh edge to start sloping seaward. Panel C. The outer block of peat has recently cracked and will ultimately break off of the platform and slowly disintegrate in response to continued wave and biological activity. Panel D. If wave energy is high enough and the marsh peat consists of alternating layers of sand (stormy periods) and peat growth (non-stormy periods), the marsh can erode by stripping off successive peat layers from the upper surface as shown in this photo. Photographs are by S. Riggs.

## References:

Earth Sciences and Image Analysis Laboratory, NASA Johnson Space Center. Image STS 095-709-14 (*http://eol.jsc.nasa.gov*).

North Carolina Geological Survey (*http://www.geology.enr.state.nc.us*).

National Oceanographic and Atmospheric Administration (NOAA) National Water Level Observation Network (*www.co-ops.nos.noaa.gov/*).

Riggs, S.R., and Ames, D.V., 2003, Drowning of North Carolina: Sea-Level Rise and Estuarine Dynamics: NC Sea Grant College Program, Raleigh, NC, Pub. No. UNC-SG-03-04, 152 pp.

U.S. Geological Survey (*http://ga.water.usgs.gov/edu/watercycle.html*).

# Appendix: Student Handouts

Part 1

Lesson 2:
- (ii)Figure 1-5
- (iii)Figure 1-4
- (iv)Figure 1-3

Lesson 3:
- (v)Figure 1-6
- (vi)Figure 1-7
- (vii)Group assignment related to Figure 1-6

Lesson 4:
- (viii)Figure 1-8
- (ix)Data Table: Water Cycle Processes

Lesson 5:
- (x)Figure 1-9
- (xi)Figure 1-2

Lesson 6:
- (xii)Figure 1-10
- (xiii)Figure 1-11

Lesson 7:
- (xiv)Figure 1-12
- (xv)Data Table

Lesson 8:
- (xvi)Figure 1-14
- (xvii)Figure 1-16

Lesson 12:
- (xviii)North Carolina Beaches
- (xix)Data Table: Beach Materials

Lesson 14:
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- (xxiv)Figure 1-29
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- (xxvi)Figure 1-30
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- (xxix)Figure 1-36

Part 2

Lesson 1:
- (xxx)Class Assignment
- (xxxi)Reading #1
- (xxxiii)Reading #2

Lesson 2:
- (xxxv)Instructions: Island Profile
- (xxxvi)Table 2-1
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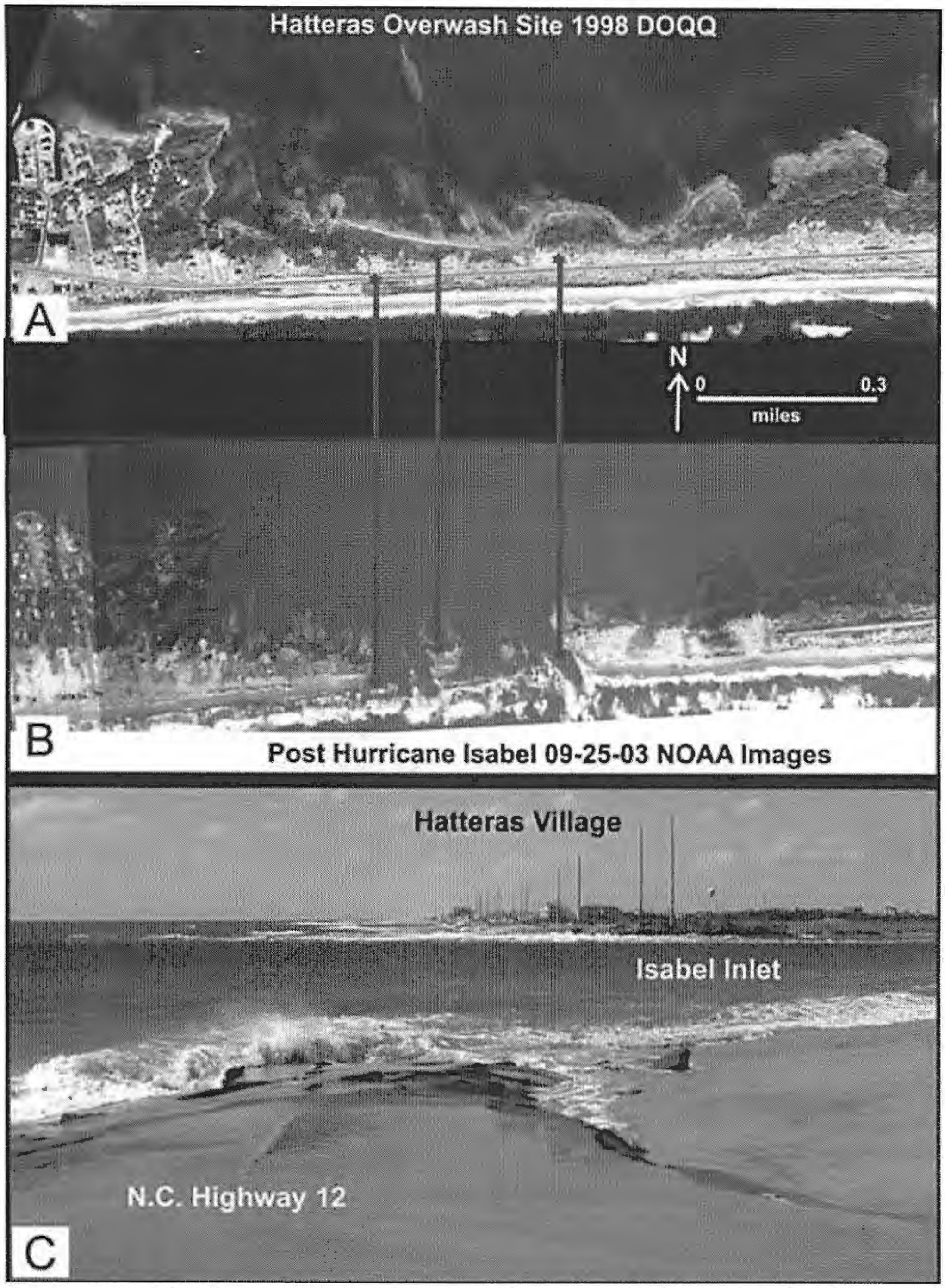
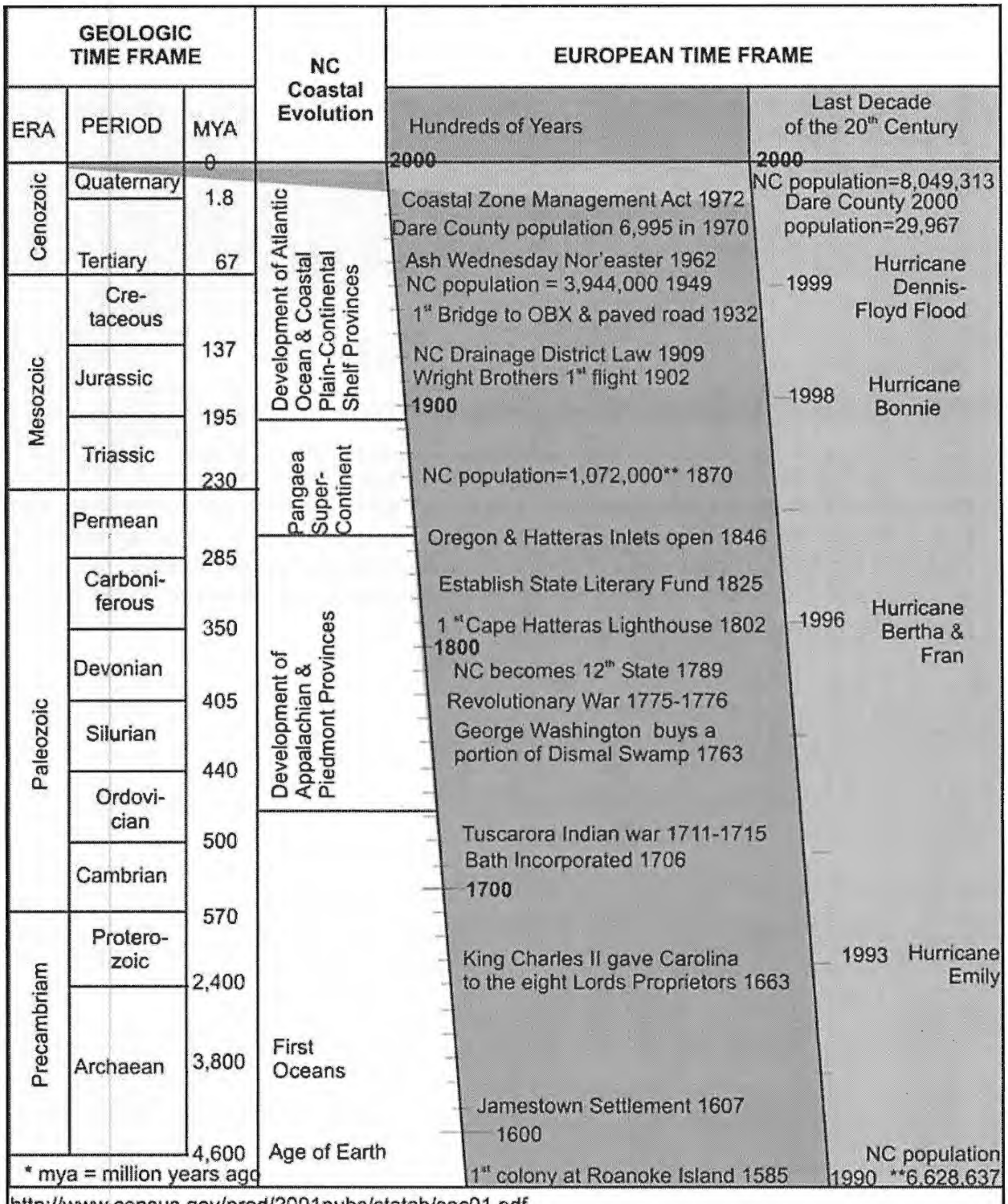
Lesson 3:
- (xxxix)Instructions: School Yard Profile
- (xli)Topographic Profile Data Sheet
- (xlii)Scenario: Research Vessel
- (xliii)Table 2-3

Lesson 4:
- (xliv)Instructions: Hurricane Floyd



<u>Figure 1-5.</u> Aerial and ground photographs show the site of Isabel Inlet that opened on Sept. 18, 2003 in response to Hurricane Isabel. <u>Panel A.</u> A 1998 false color aerial photograph shows the east end of Hatteras Village and the potential inlet site. <u>Panel B.</u> An aerial photograph of the same area taken on Sept. 25, 2003 shows the location and three-part character of Isabel Inlet. The red points and associated lines on Panels A and B represent exact common points. <u>Panel C.</u> A ground level photo looks west across Isabel Inlet toward Hatteras Village with the "going-to-sea" N.C. Hwy. 12 in the foreground. Figure 8-4-18, p. 141 in Riggs and Ames (2003).



http://www.census.gov/prod/2001pubs/statab/sec01.pdf

**Figure 1-4.** This geologic time chart contrasts long-range geologic time that reaches 4.6 billion years back to the earth's formation with the more recent human time frame since European colonization of North Carolina (the last 400 years) and the last decade of the 20th century.

**The correct date for the Coastal Zone Management Act is 1972, as cited above.**

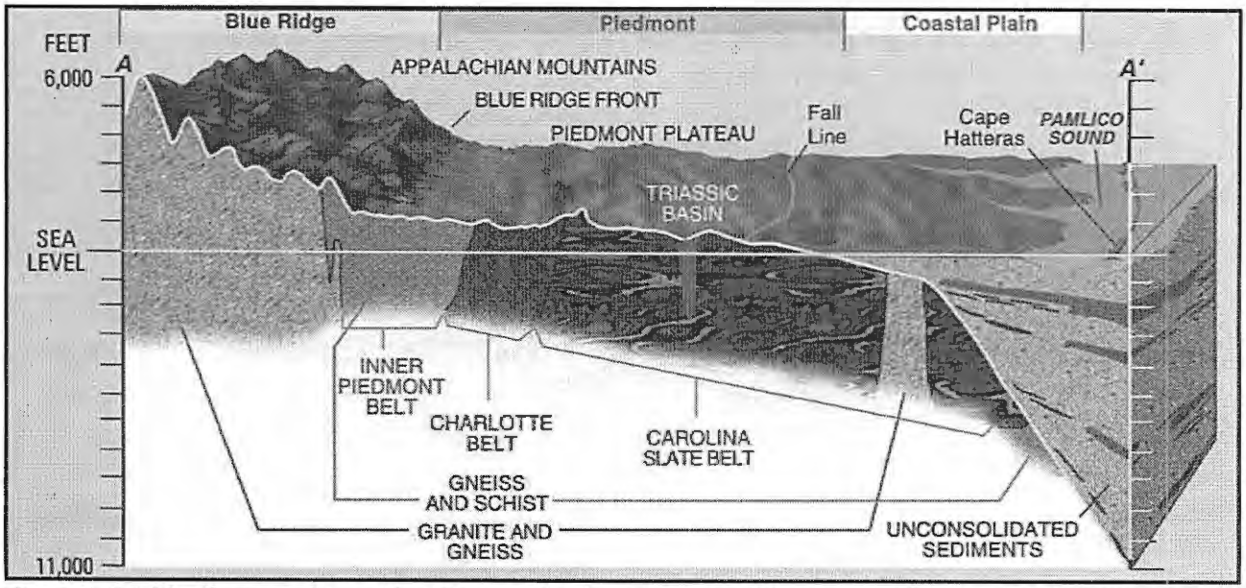


**Figure 1-3. This diagram shows the three geologic provinces of North Carolina. See Table 1 for a brief evolutionary history of the provinces. The young Coastal province was produced largely from sediments that were being weathered and eroded off the older and higher Appalachian and Piedmont provinces. The sediments were carried to the ocean by the river drainage system and deposited in the shallow coastal and marine environments of the more recently formed Atlantic Ocean (*http://www.geology.enr.state.nc.us*).**

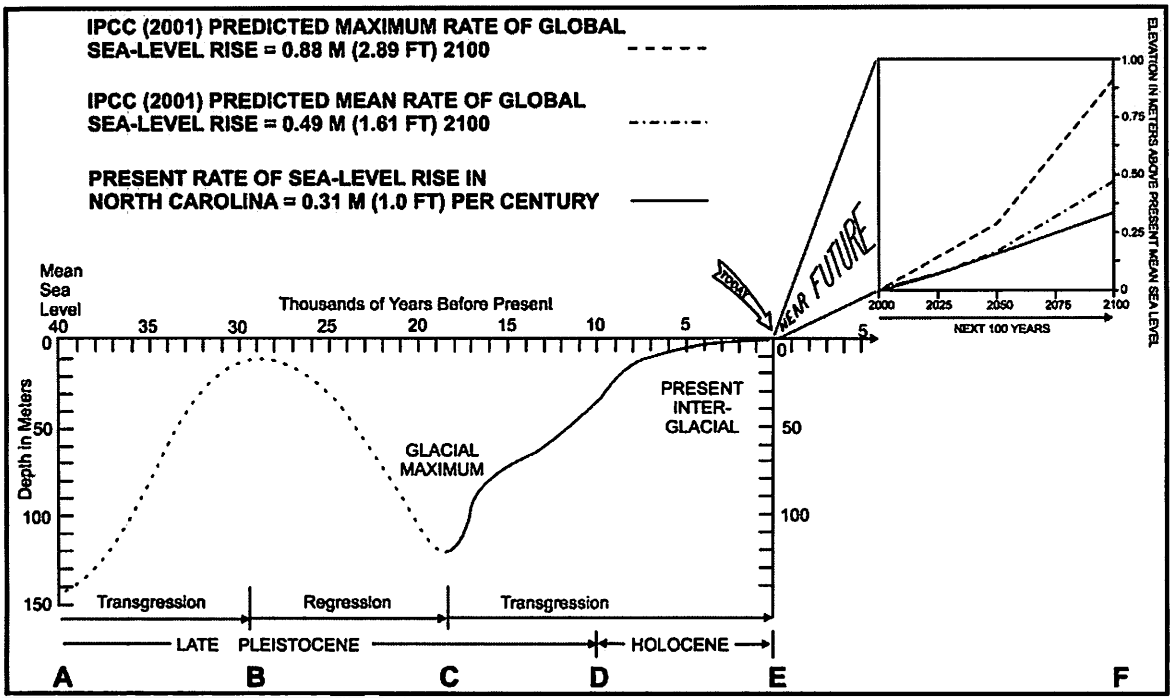


**Figure 1-6**. Generalized sea-level curve for the past 40,000 years and predictions to year 2100 AD. Predictions are based upon IPCC (2001). Figure 6-2-1, p. 62 in Riggs and Ames (2003).

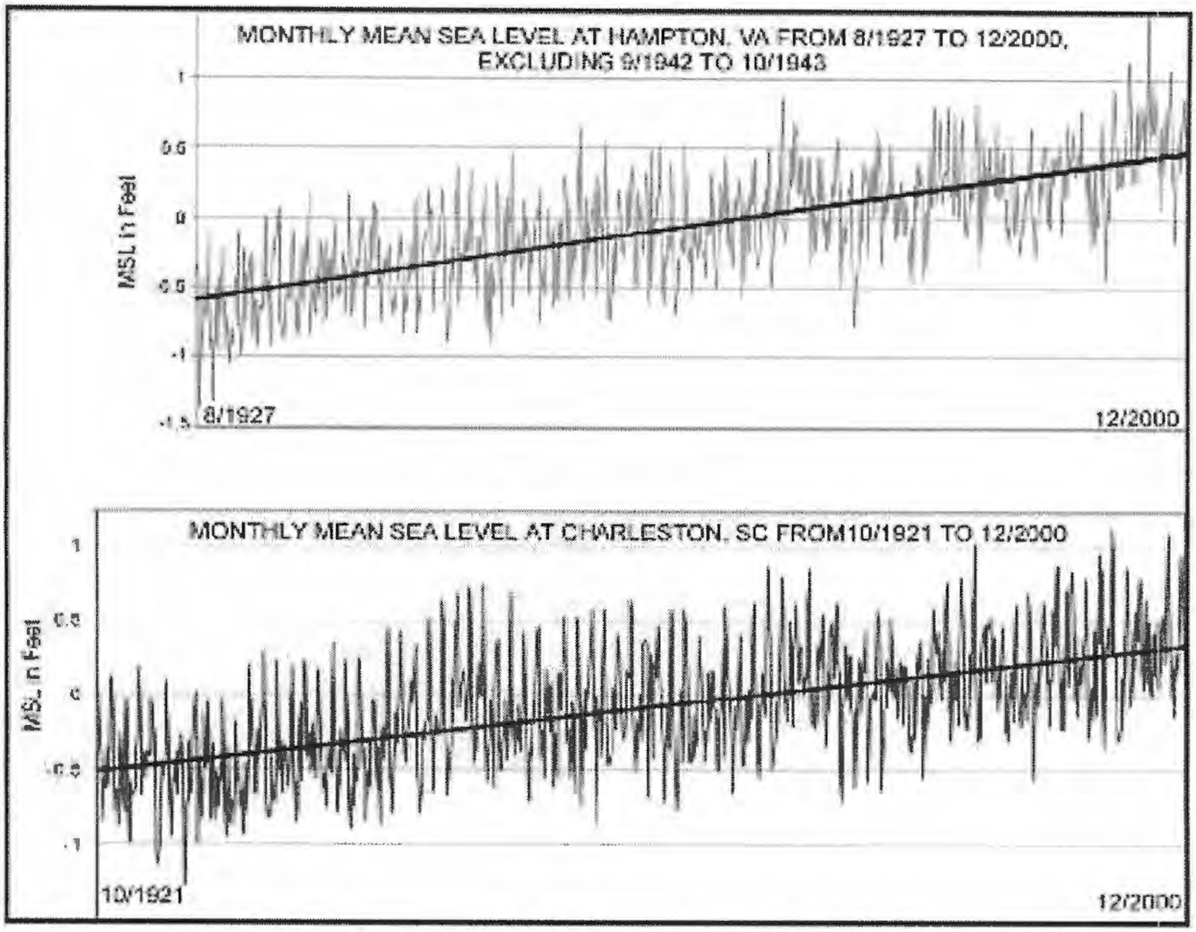


Figure 1-7. Tide gauge data from Hampton, Va. and Charleston, S.C. demonstrate the rate of ongoing sea-level rise. The plotted data are monthly averages of mean sea level that extend from August 1927 and October 1921, respectively, to December 2000. The heavy line through each plot is the graphical representation of the data trend in a series. It is obtained by regression analysis and shows the net rise in sea level during this time period. Similar tide-gauge data developed at Duck, N.C.by the U.S. Army Corps of Engineers only goes back to 1980, but in a 20-year time period, the data suggest a slightly higher rate of sea-level rise of about 1.5 ft/100 yrs for the Albemarle Sound coastal region. The two sets of tide-gauge data in Figure 1-7 are from the National Oceanographic and Atmospheric Administration (NOAA) National Water Level Observation Network (*www.co-ops.nos.noaa.gov/*). Figure 6-3-2, p. 65 in Riggs and Ames (2003).

Work in groups to answer the following questions related to Figure 1-6.

1. Use Figure 1-6 to answer the following questions.
    a. What does the vertical axis (y axis) represent?
    b. What units are used on the vertical axis?
    c. What is the significance of the graph going from 0 to 150 in the negative direction?
    d. What does the horizontal axis (x axis) represent?
    e. What units are used on the horizontal axis?
    f. What does 10 on the x axis represent?
    g. How is the x axis in the insert different from that of the main graph?
    h. Note the arrow that says "Today." If you were standing on the estuarine shoreline at Morehead City today, what is the mean sea level at that point? Where was the beach 40,000 years ago?
    i. What is happening to the glaciers and sea level between B and C?
    j. What is happening to glaciers and sea level between C and D?
    k. What is happening to sea level between D and E? E and F?
2. From your answers to questions 1a-k, make a statement concerning the relationship between glacier changes and sea-level changes.
3. What does the slope of a line represent on a graph? How would you describe the rate of change in sea level between B and C? C and D? D and E?
4. What do the three lines in the insert (E-F) represent?
5. What inference might you make in the relationship of predicted sea-level change to climate change and the resulting differences in glacial melting rates for the next 100 years?
6. Where was sea level at the beginning of the Holocene when modern human civilization began?
7. If you were standing at the location of today's estuarine shoreline in Morehead City in the year 2100, how much water would you be standing in if sea-level rise continues at its present rate? If sea-level rises at the predicted maximum rate?

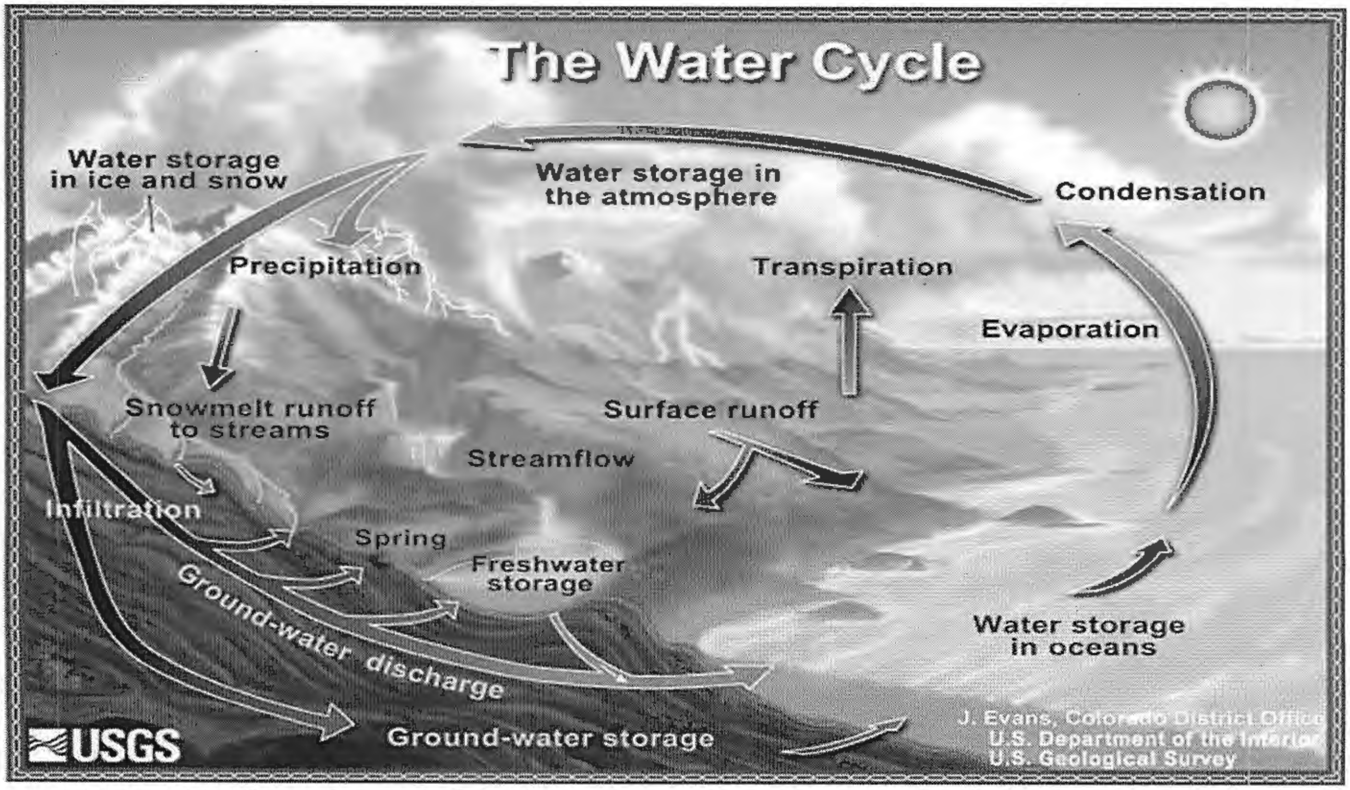


**__Figure 1-8.__ The water cycle is fueled by energy from the sun and aided by the force of gravity. Figure is by J. Evans and is from the U.S. Geological Survey (*http://ga.water.usgs.gov/edu/watercycle.html*).**

Data Table: Water Cycle Processes

| Process | Description of Process | Influences that Affect the Process (explain) |
|---|---|---|
| Condensation (Example) | The process by which water vapor (gas) changes into liquid (operational definition) | As the temperature decreases, molecules lose energy and slow down, causing them to move closer together. When the attraction between them is great enough, they clump together and form liquid droplets. |
| Evaporation | | |
| Transpiration | | |
| Precipitation | | |
| Surface Run-off | | |
| Ground Water Discharge | | |
| Infiltration | | |

Use Figure 1-8 to answer the following questions:

1. Complete *Data Table: Water Cycle Processes* above and discuss the associated processes. An operational definition explains in everyday language what a word represents and its relationship to other concepts. You can probably devise a definition just by looking at the illustration. An example is given to help you.
2. Under what conditions might water molecules that fall to the earth as precipitation take hundreds to thousands of years to return to the atmosphere?
3. Do clouds formed over the ocean precipitate salty rain water? Explain.
4. The water cycle redistributes heat energy on earth. Explain the role of evaporation and condensation in that process.
5. How are the natural processes of evaporation and condensation related to the distillation of water?
6. Solar energy also influences the movement of air masses. Refer to appropriate reference books and explain the relationship between differential heating, movement of air masses, wind, and waves.
7. What is the relationship between the sun's energy and the movement of sand on the beach? Illustrate your answer with a diagram.

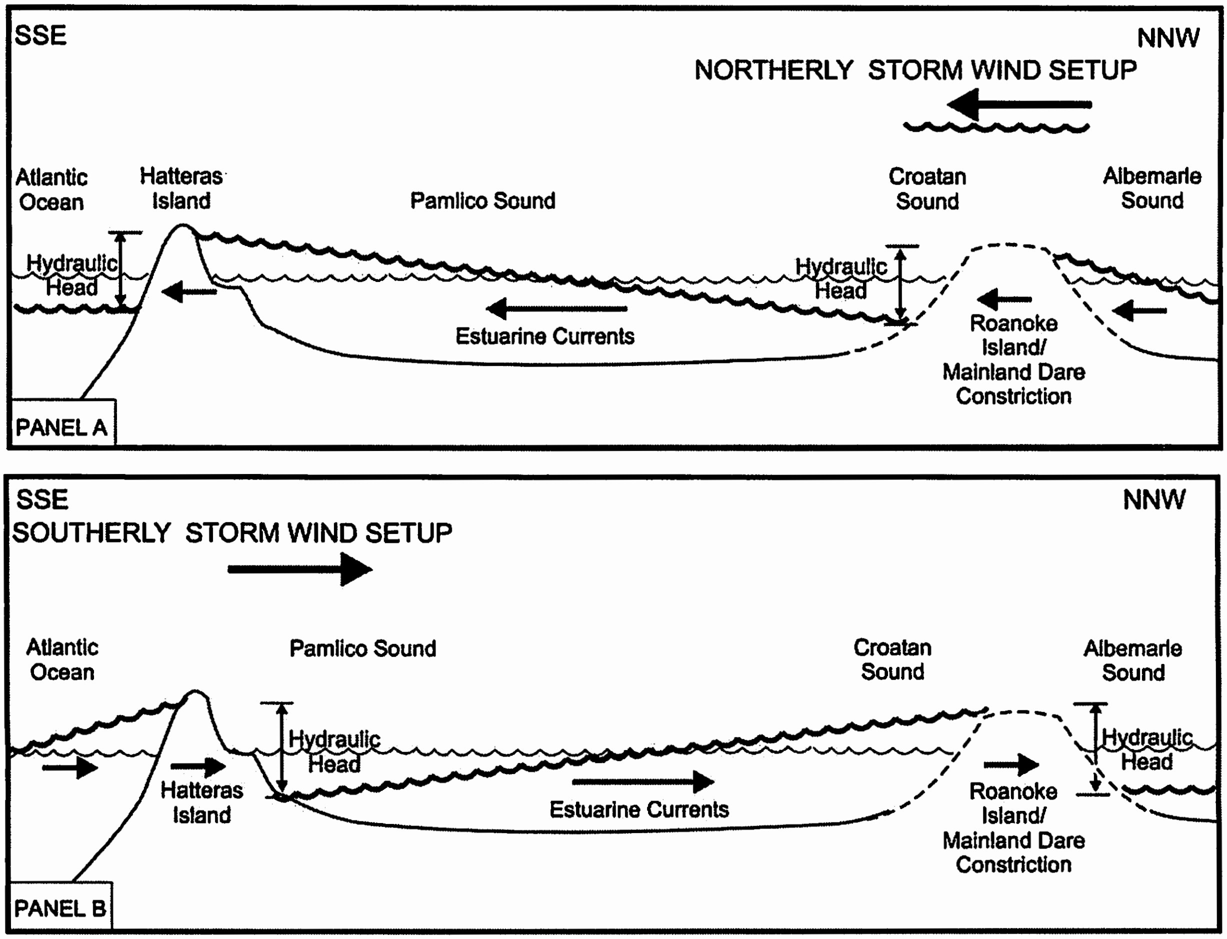


**Figure 1-9.** Model of estuarine storm tides in the North Carolina sounds that form in response to different storm events. Wave energy added to both high and low storm tides is the primary process driving estuarine shoreline recession. Panel A. High storm tides occur along southern shores in response to events dominated by northeast, north, or northwest wind directions, whereas low storm tides occur along the northern shores. Panel B. High storm tides occur along the northern shores resulting from events dominated by winds from the west, southwest, or south wind directions, whereas low storm tides occur along the southern shores. Figure 5-2-1, p. 57 in Riggs and Ames (2003).

Figure 1-2. This satellite image shows the Sea-View site locations. The image is a joint product of the NASA Landsat Project Occupancy Office, Goddard Space Flight Center, and the U.S. Geological Survey EROS Data Center. Figure is modified from Figure 2-1-3, p. 19 in Riggs and Ames (2003)

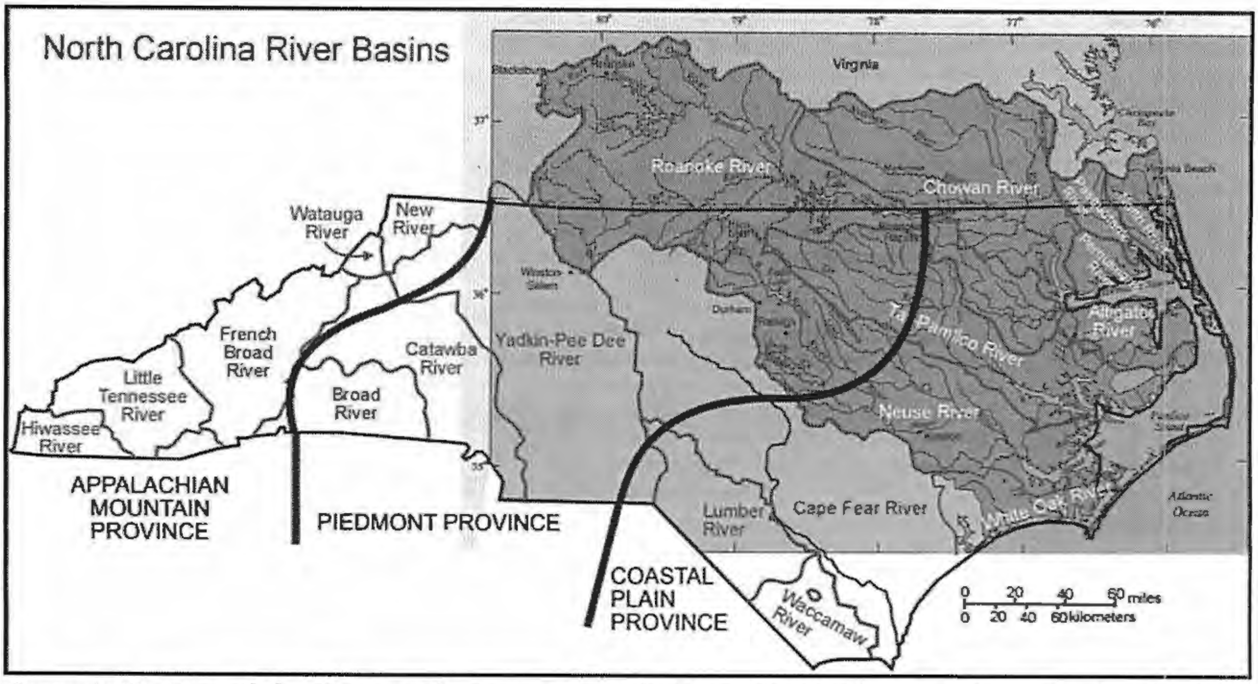


Figure 1-10. Map of the three geologic provinces (outlined in black) and drainage basins (outlined in red). The river basins underlain by green color and with the blue drainages drawn in, flow to the Atlantic Ocean and produce the vast northeastern North Carolina coastal system. Figure 2-1-1, p. 17 in Riggs and Ames (2003).
(Colors may be seen on the slide.)

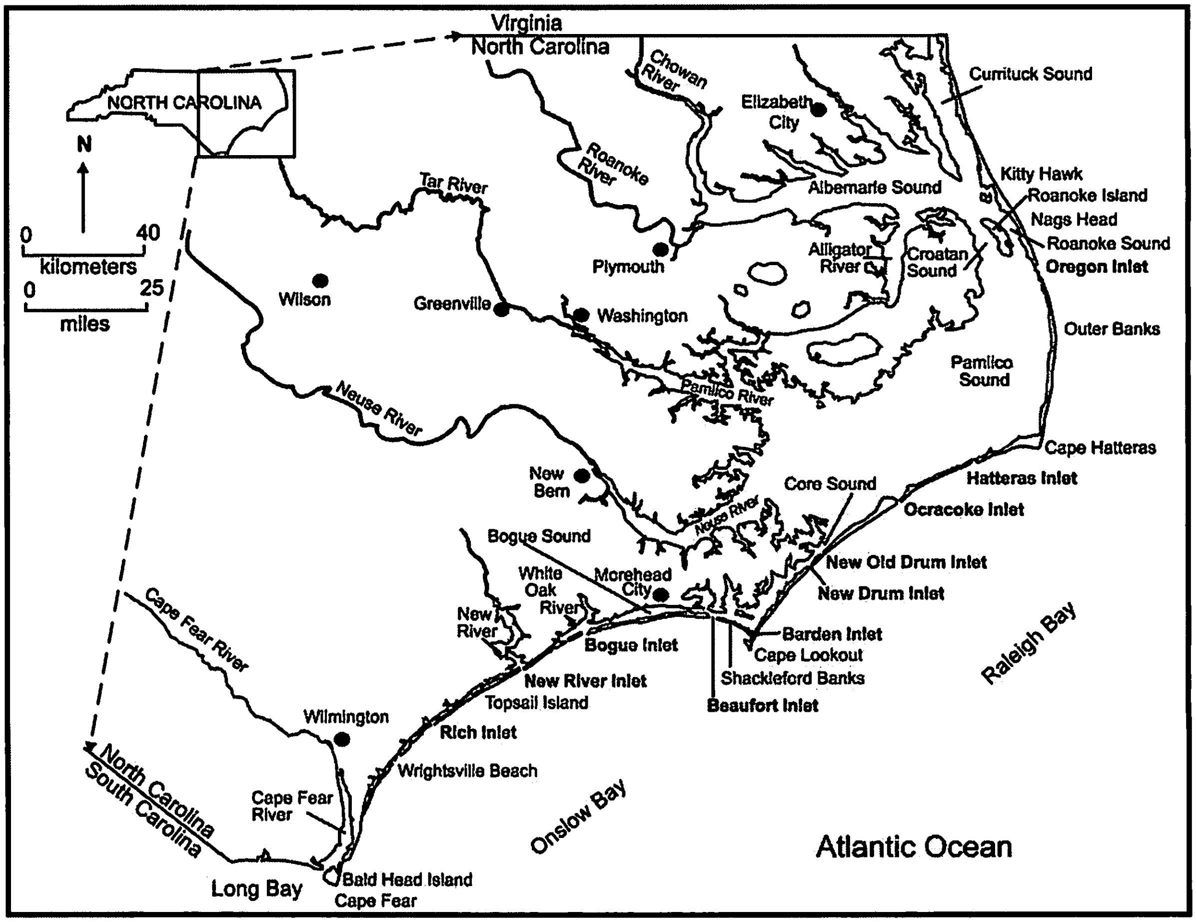


**Figure 1-11.** Location map shows major towns and coastal features for the North Carolina coastal system. Figure 2-1-2, p. 18 in Riggs and Ames (2003).

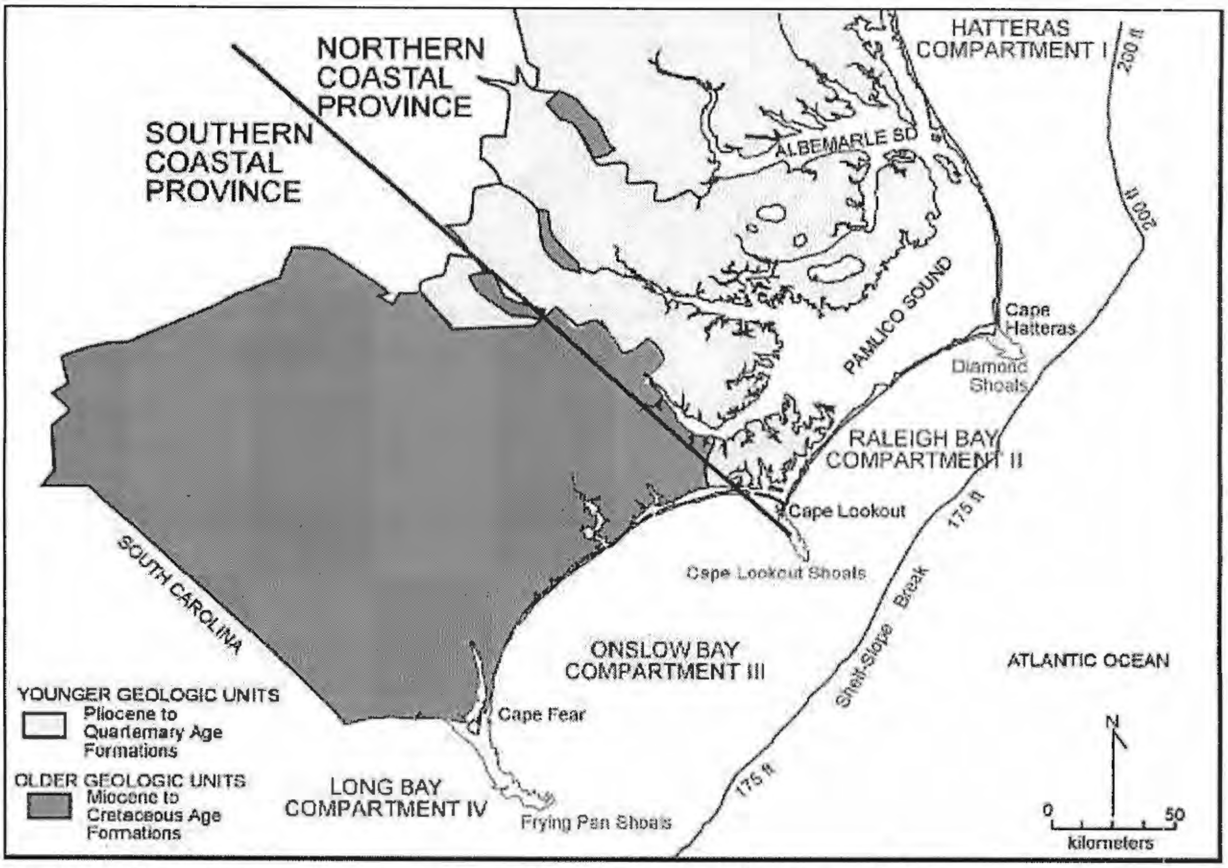


**Figure 1-12.** Generalized geologic map of the North Carolina Coastal Plain shows the two coastal provinces and four geomorphic compartments of the coastal system. Geologic outcrop patterns are summarized from the *Geologic Map of North Carolina* (NCGS, 198S). Figure 2-2-1, p. 21 in Riggs and Ames (2003).

Data Table

| | Hatteras Compartment | Raleigh Bay Compartment | Onslow Bay Compartment | Long Bay Compartment |
|---|---|---|---|---|
| Direction the coast faces | | | | |
| Type of storms that most frequently affect the coast | | | | |
| Width of the continental shelf | | | | |
| Age of rocks forming continental shelf | | | | |

Explain why wave energy is greater in the north than in the south. Why is Cape Hatteras a destination for surfers?

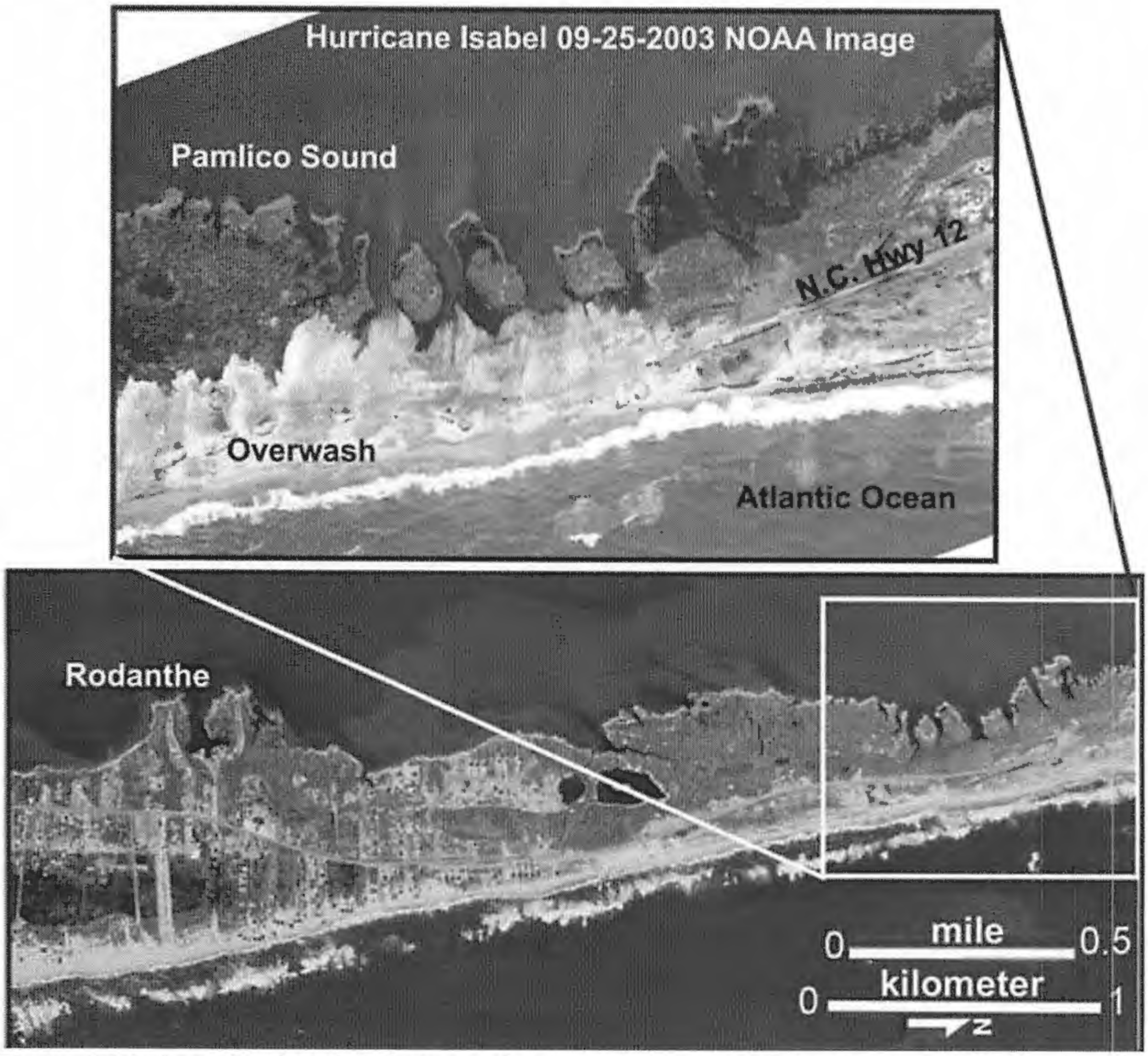


Figure 1-14. Pea Island aerial photographs show a segment of simple overwash barrier island just north of Rodanthe. The bottom panel is a 1998 aerial photograph of Pea Island with a box indicating the area in the NOAA 2003 post-Hurricane Isabel aerial photograph in the upper panel. Hurricane Isabel caused extensive overwash that buried N.C. Hwy. 12. The overwash sands add critical elevation to the barrier and width if the overwash sands are carried across the island to the estuarine side. Many houses in north Rodanthe were either destroyed or severely damaged in this storm.

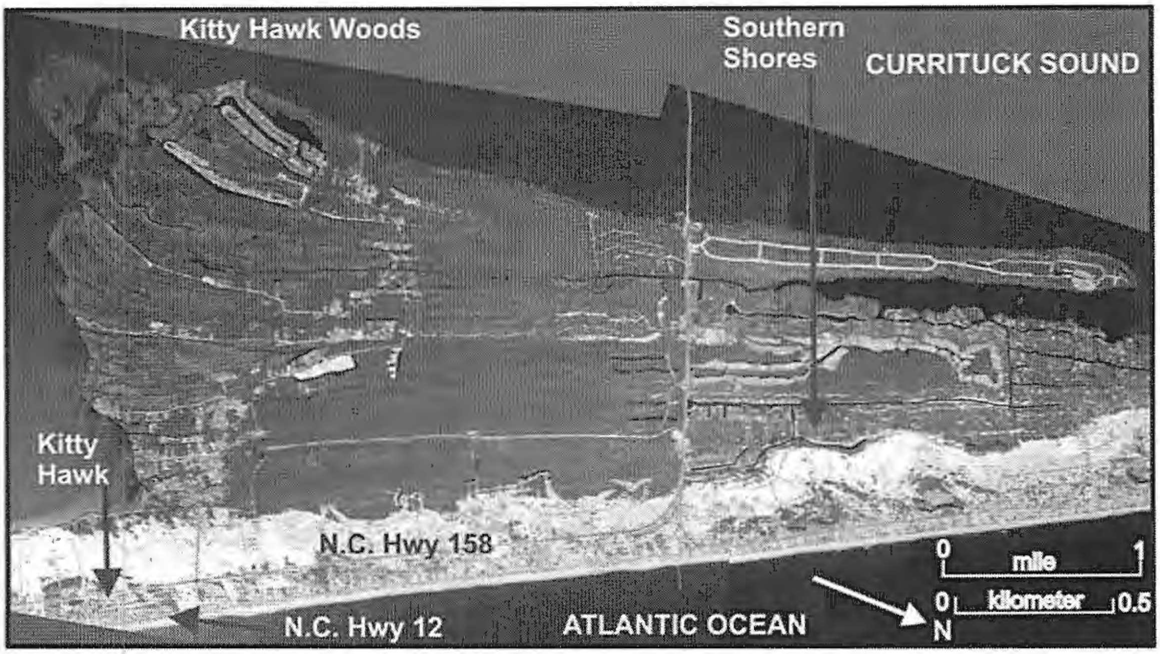


Figure 1-16. A 1982 infrared aerial photograph of Kitty Hawk shows the extensive sequence of beach ridges that constitute Kitty Hawk Woods. This is an example of a complex barrier island. The red color in this false color image taken in the winter, is photosynthesizing plants (e.g. pines, bay trees, live oaks etc.), whereas the gray-green color represents the marsh grasses. The white zone west of N.C. Hwy. 158 is a series of slightly developed back-barrier dunes, whereas the white zone east of N.C. Hwy. 158 is the highly developed active beach. Figure 4-5-3, Panel A, p. 52 in Riggs and Ames (2003).

## North Carolina Beaches:

The sand beaches on North Carolina's barrier islands are composed mainly of quartz sand, with varying amounts of abraded shell material and local areas with minor concentrations of black heavy mineral sand and river gravel. The quartz sand and associated black sand and river gravel were derived from eons of erosion in the Piedmont and Appalachian provinces. Subsequently through time, rivers along the Atlantic margin transported these eroded sediments into the coastal region and deposited them as riverine channel fills and delta deposits. With fluctuating sea level, these old riverine deposits have been eroded and reworked many times into various coastal deposits and finally into the present barrier islands. The shell component consists only partly of modern shells of organisms presently living within the surf zone and associated continental shelf environments. Most of the shells on the North Carolina beaches are fossils that range in age from thousands to hundreds of thousands years old.

The most abundant shells on many beaches are the gray to black-stained oysters (*Ostrea virginica*), which live only in the estuaries behind the barriers. They lived, died, and were deposited in the mud and peat sediments that form in the back-barrier marshes. In response to ongoing sea-level rise, the barrier islands migrate upward and landward over the back-barrier marsh deposits. With time these marsh deposits, along with the included oysters, crop out in the surf zone, erode during storms, and are supplied back to the beach as blocks of peat and fossil oysters. This represents an important source of "new" sediment that continues to feed the beach through time. The oysters generally date from a few hundred to several thousands of years in age.

The orange iron-stained shells on the beach often range from tens to hundreds of thousands of years old. Many of these shells were on the surface of the continental shelf during the last glacial episode (20,000 to 14,000 years ago). During this time period, the North Carolina shoreline was below the outer continental shelf, about 425 feet below present sea level and between 15 to 60 miles offshore of the modern shoreline. During this period, the continental shelf was part of the Coastal Plain, and these shells occurred within the soil profile that developed on the exposed surface of the continental shelf and became iron stained by the soil that developed on the sediment surface.

Among the largest shells found on the beach are the quahogs or cherrystone clams (*Mercenaria mercenaria)*. Some of these shells that contain the beautiful purple coloration on the inside of the clam shell are modern in age. These clams live on the adjacent sand flats within inlet ebb and flood-tide deltas. However, most of these shells range from bleached white to dark amber brown and are often tens to hundreds of thousands of years old. These older *Mercenaria* shells are being eroded out of older layers formed during the Pleistocene and cropping out on the shore face and inner continental shelf during storms. Notice that many of these shells, once they are on the beach, eventually break down in the 'ball mill' of the high-energy surf zone into smaller sized particles—severely abraded gravels and much finer grained, flat and rounded shell sand grains. It is this fine gravel and coarse sand shell material that gives the beaches their variable orange colorations as you look across the beach. Most medium and fine-grained sand beaches are gray colored due to the dominance of quartz sand with a total lack of shell particles among this grain size fraction.

The black heavy mineral sands are composed of various types of very hard and chemically stable heavy minerals. The dominant black minerals (illmenite and magnetite) include lesser abundant red minerals (garnet and rutile) and the rare pale green and blue minerals (tourmaline, zircon, apatite, etc.). Because these minerals are much heavier and denser than quartz and calcite, they tend to be fine to very fine sand size grains and occur with coarser grained fractions of quartz and calcite sand. Consequently, the heavy mineral sands tend to occur in the upper portions of the storm beach and are particularly concentrated around inlets and capes.

## Beach Materials

| Type | Source | Appearance | Location on the beach |
|---|---|---|---|
| Quartz sand | | | |
| Shell materials (oysters) | | | |
| Shell materials (*Mercenaria*) | | | |
| Heavy Minerals | | | |
| River gravels | | | |

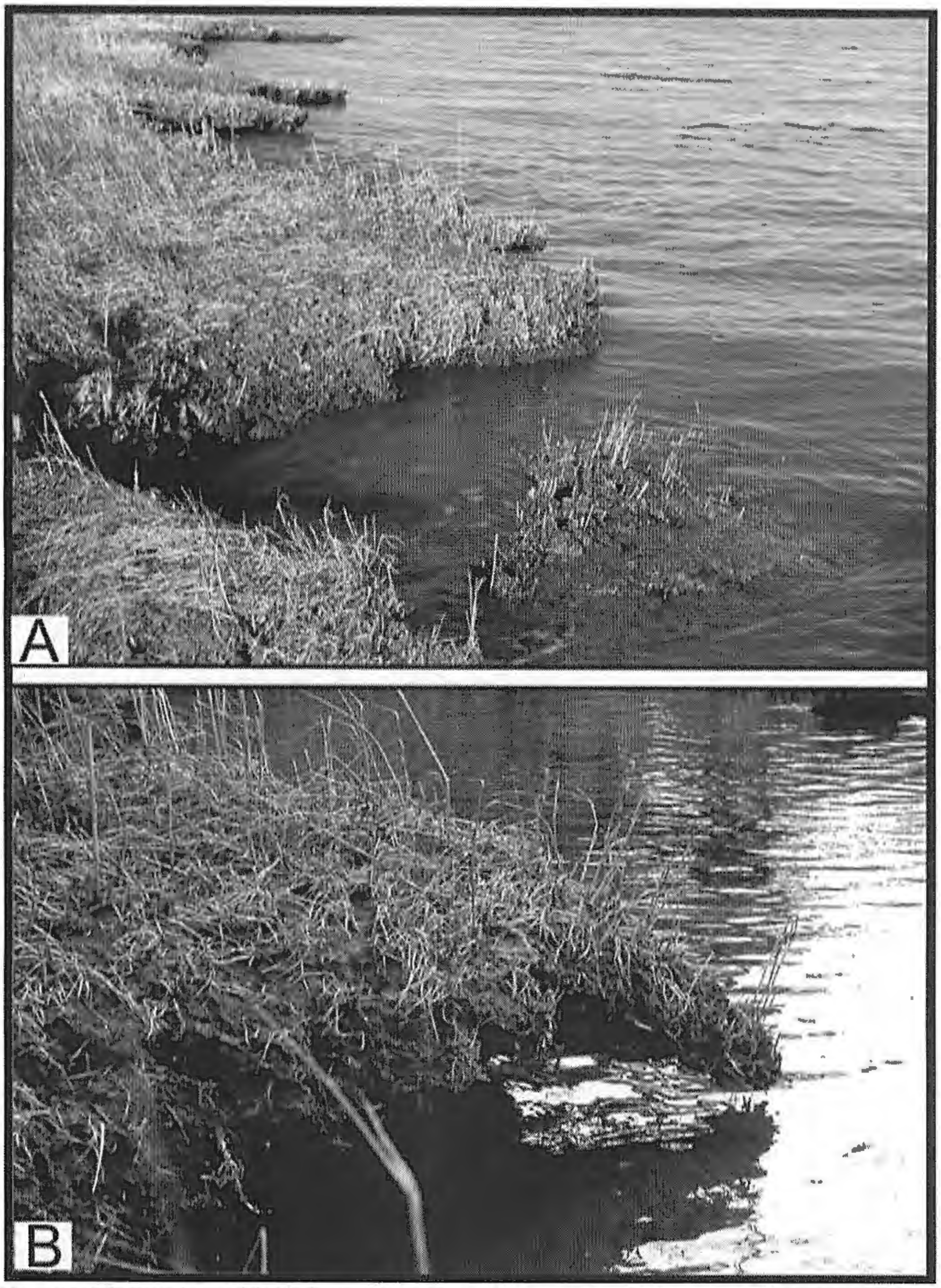
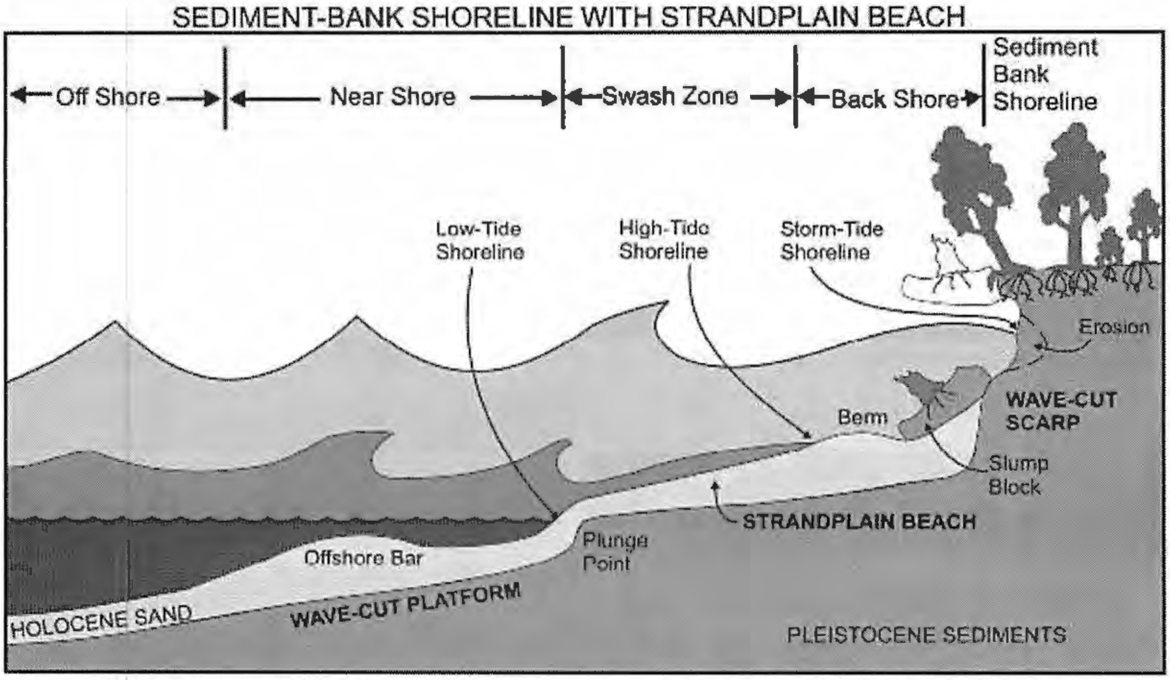


Figure 1-24. Panel A. A highly irregular and eroding marsh platform shoreline occurs at Wades Point along the Pamlico River, Beaufort County. Nags Head Woods has similar steeply scarped and undercut platform marshes. The upper peat is bound by a dense root mass of modern marsh plants. Below this root mass, the peat is decomposed, very soft, and highly erodible. As the platform is undercut, large blocks of the upper bound peat break off as can be seen in the lower right hand corner. Figure 8-4-1 Panel F, p. 124 in Riggs and Ames (2003). Panel B. Wave action during low tide levels erodes the soft peat layer underlying the tough root-bound modern marsh surface to produce this severely undercut peat block. During higher water levels, wave energy causes the root-bound overhang to break off—this is the mechanism for eroding marsh shorelines. Figure 8-2-16, Panel D, p. 96 in Riggs and Ames (2003).



**<u>Figure 1-25</u>. Schematic model of a sediment-bank shoreline shows the following geomorphic features: 1) A wave-cut scarp and wave-cut platform have been eroded into older sediment units with a strandplain beach perched on the platform. 2) Different water levels and wave sizes that do the work of shoreline erosion, beach building, and beach maintenance. 3) The process of eroding and undercutting the bank top during high storm tides and subsequent slumping and reworking of slump blocks to produce the beach sediments. Figure 4-2-1, p.38 in Riggs and Ames (2003).**

Figure 1-26. A high sediment-bank shoreline in Nags Head Woods is being severely eroded by the wave energy along the eastern end of Albemarle Sound. However, erosion is not occurring during the low-energy conditions shown in this photo. Rather, bank erosion occurs during storm conditions when the water level oversteps the beach and directly intersects the sediment-bank. Notice the extensive strandplain beach that is derived from the erosion of the wave-cut scarp comprised of a sand sediment-bank. This Figure is on p. 24 in Riggs and Ames (2003).

## Beach Plants

| Species | Relative Salt Tolerance | Relative Water Level |
|---|---|---|
| Sea oats | | |
| Bull rushes | | |
| Wax myrtle | | |
| Marsh elder | | |
| Cattails | | |
| Marsh glasswort | | |
| Salt marsh cordgrass | | |
| Black needle rush | | |
| Salt meadow hay | | |
| Eel grass | | |

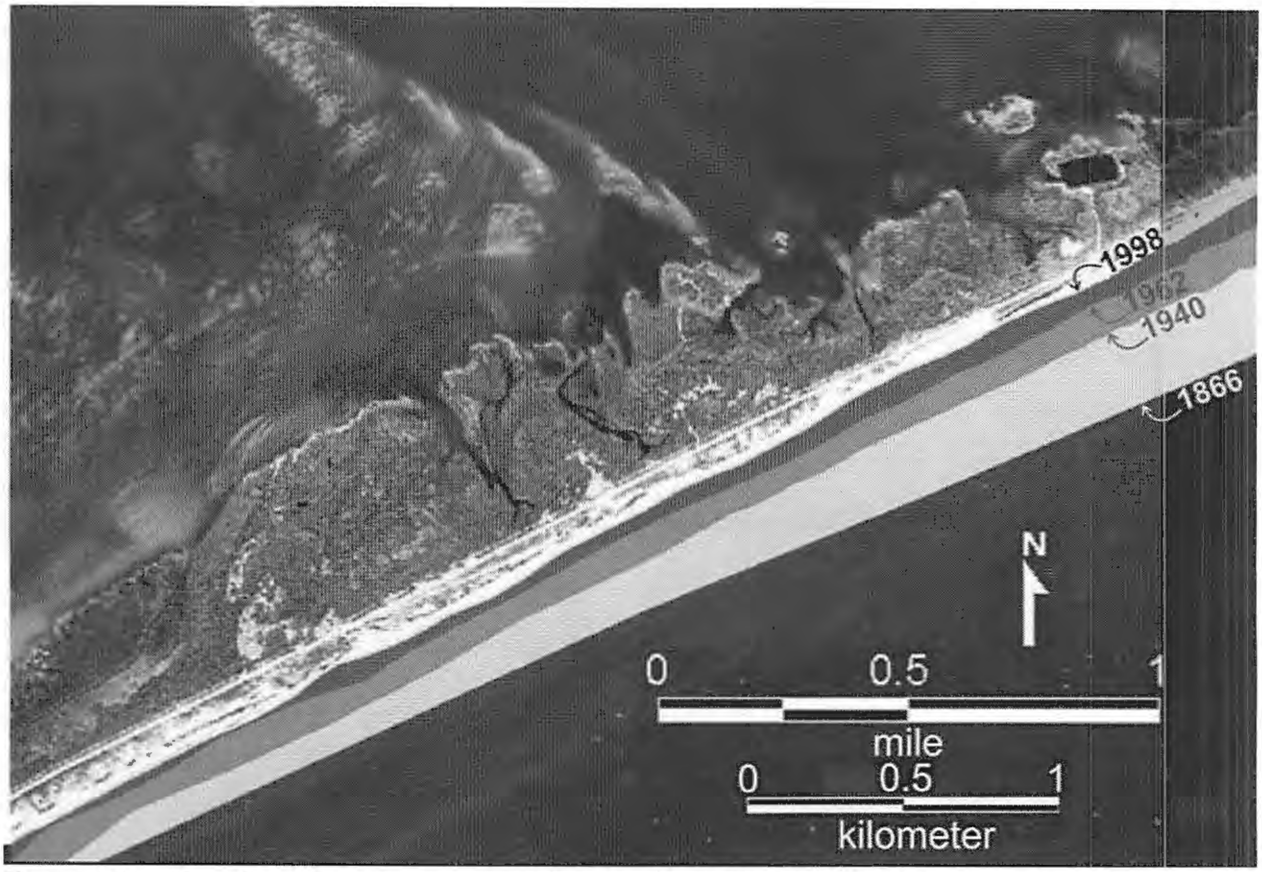
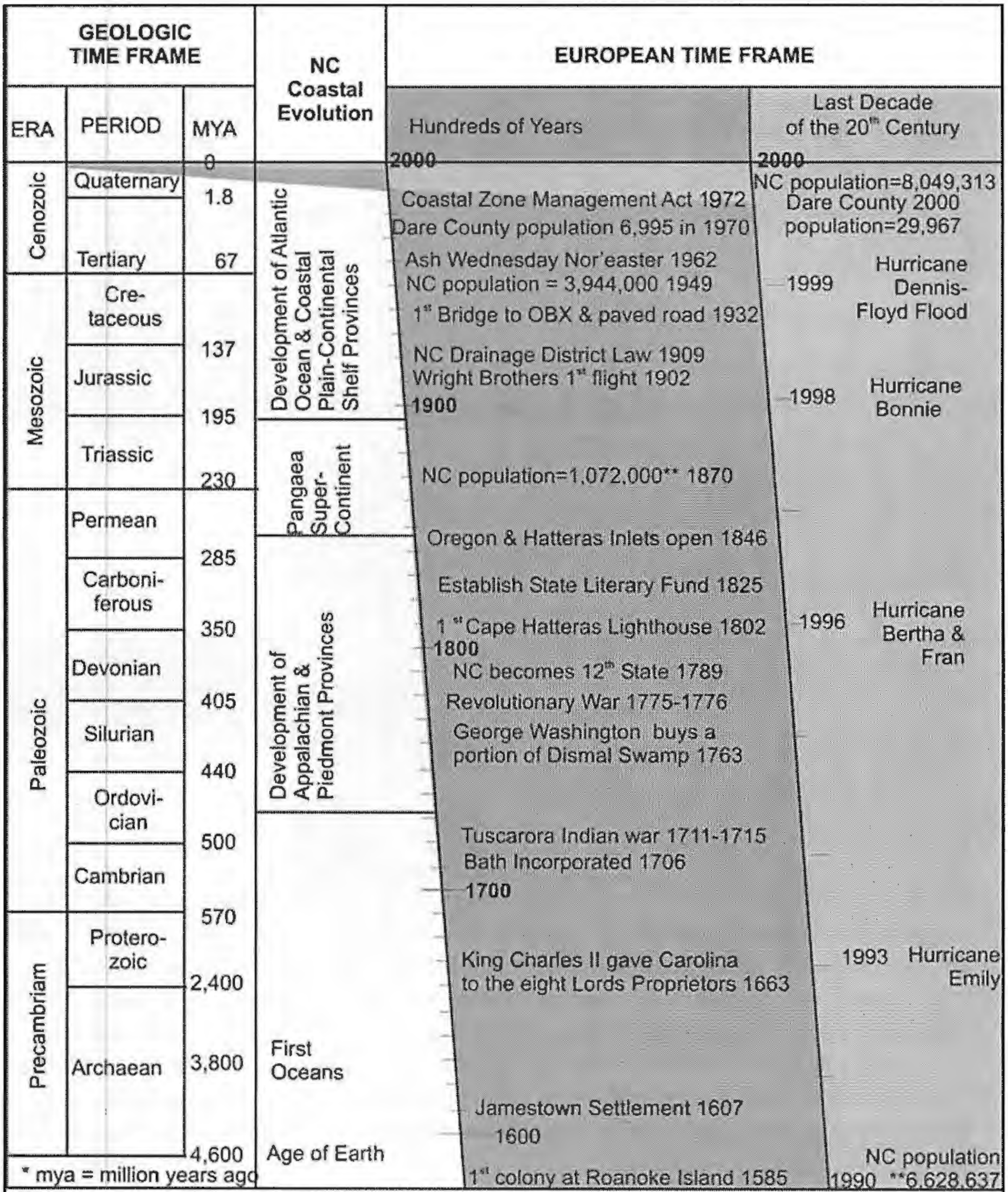


Figure 1-29. **Shoreline changes on Ocracoke Island are shown for a time period spanning 132 years (1866-1998). Yellow represents the amount of shoreline recession that occurred between 1866 and 1940; green represents the erosion between 1940 and 1962, and red represents the land lost between 1962 and 1998. (See slide for color version.)**



http://www.census.gov/prod/2001pubs/statab/sec01.pdf

**Figure 1-4.** This geologic time chart contrasts long-range geologic time that reaches 4.6 billion years back to the earth's formation with the more recent human time frame since European colonization of North Carolina (the last 400 years) and the last decade of the 20th century.

**The correct date for the Coastal Zone Management Act is 1972, as cited above.**

Figure 1-30. Two photographs of an eroding estuarine sediment-bank shoreline along the western side of the Chowan River. Panel A. Pre-Hurricane Isabel photograph was taken prior to the storm on Sept. 18, 2003. This ~75-ft high bluff consists of a lower clay bed (~30 ft thick) with an overlying sand bed (~45-50 ft thick). Panel B. The post-Hurricane Isabel photograph was taken on Oct. 6, 2003 from about the same location along the bluff shoreline as Panel A. The red dashed line in Panel A is in the same relative location as in Panel B. The average bluff shoreline recession was about 50 ft (range from about -30 to -80 ft) for the several segments of accessible bluff shoreline. Figures are the front and back cover of Riggs and Ames (2003).

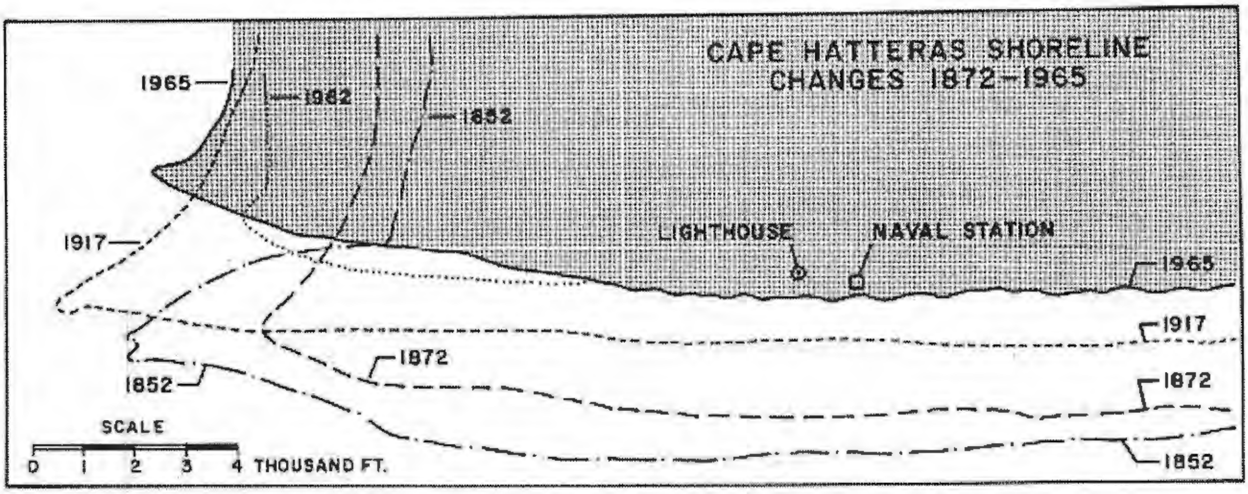
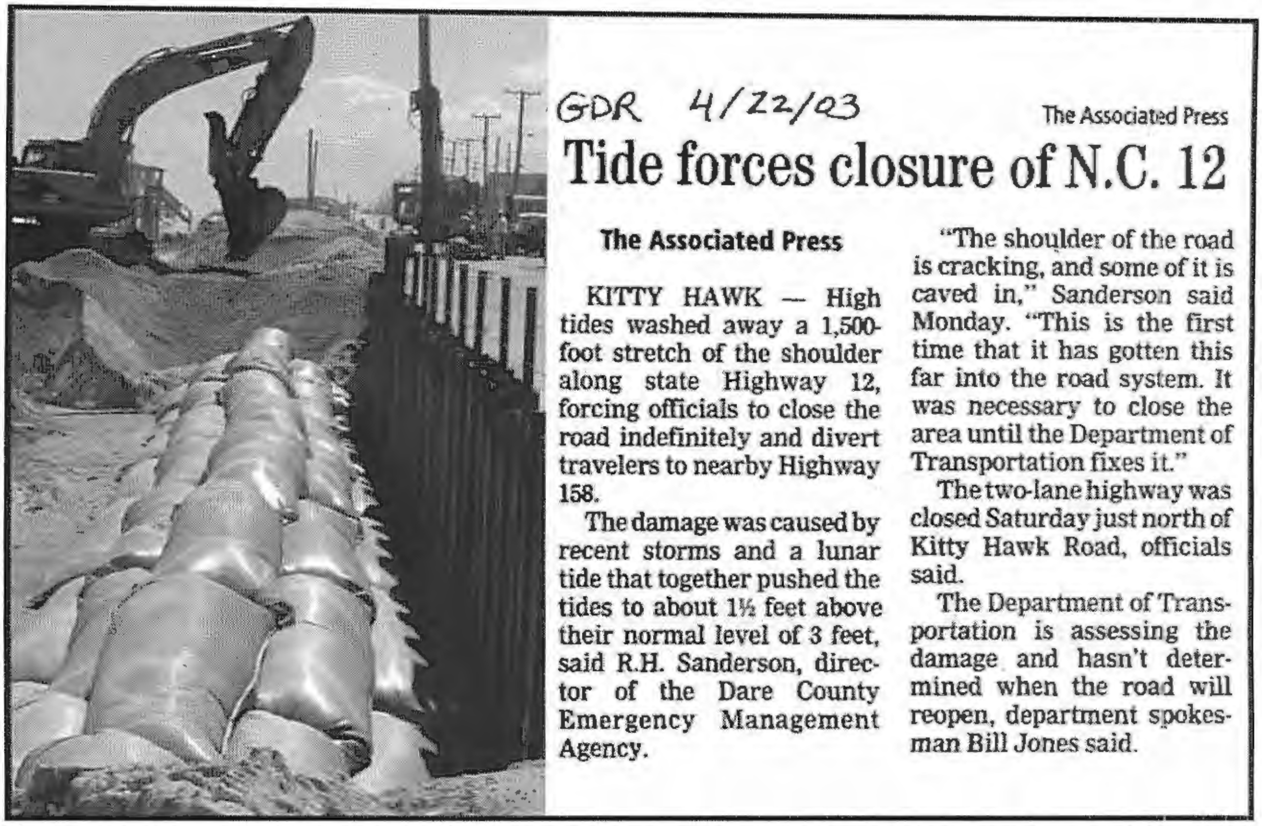


Figure 1-31. This map of historic shorelines reflects a fairly constant rate of shoreline recession for the 113 years from 1852 to 1965 in the area from Buxton to Cape Hatteras. Figure is from Fisher (1967), who modified it from the US ACE (1963). Figure 6-3-1, p. 64 in Riggs and Ames (2003).



GDR 4/22/03

The Associated Press

## Tide forces closure of N.C. 12

**The Associated Press**

KITTY HAWK — High tides washed away a 1,500-foot stretch of the shoulder along state Highway 12, forcing officials to close the road indefinitely and divert travelers to nearby Highway 158.

The damage was caused by recent storms and a lunar tide that together pushed the tides to about 1½ feet above their normal level of 3 feet, said R.H. Sanderson, director of the Dare County Emergency Management Agency.

"The shoulder of the road is cracking, and some of it is caved in," Sanderson said Monday. "This is the first time that it has gotten this far into the road system. It was necessary to close the area until the Department of Transportation fixes it."

The two-lane highway was closed Saturday just north of Kitty Hawk Road, officials said.

The Department of Transportation is assessing the damage and hasn't determined when the road will reopen, department spokesman Bill Jones said.

**Figure 1-35. A newspaper article documents damage to N.C. Hwy. 12 in Kitty Hawk with nothing more than an abnormally high spring tide, not a storm. This segment of beach has already lost the ocean front homes and is now working on the road, which has been repaired and rebuilt many times in the last decade. The photograph was taken on March 30, 2003 and the date of the newspaper article was April 22, 2003. Photograph is by S. Riggs. Article is used with permission of *The Daily Reflector*, Greenville, N.C.**

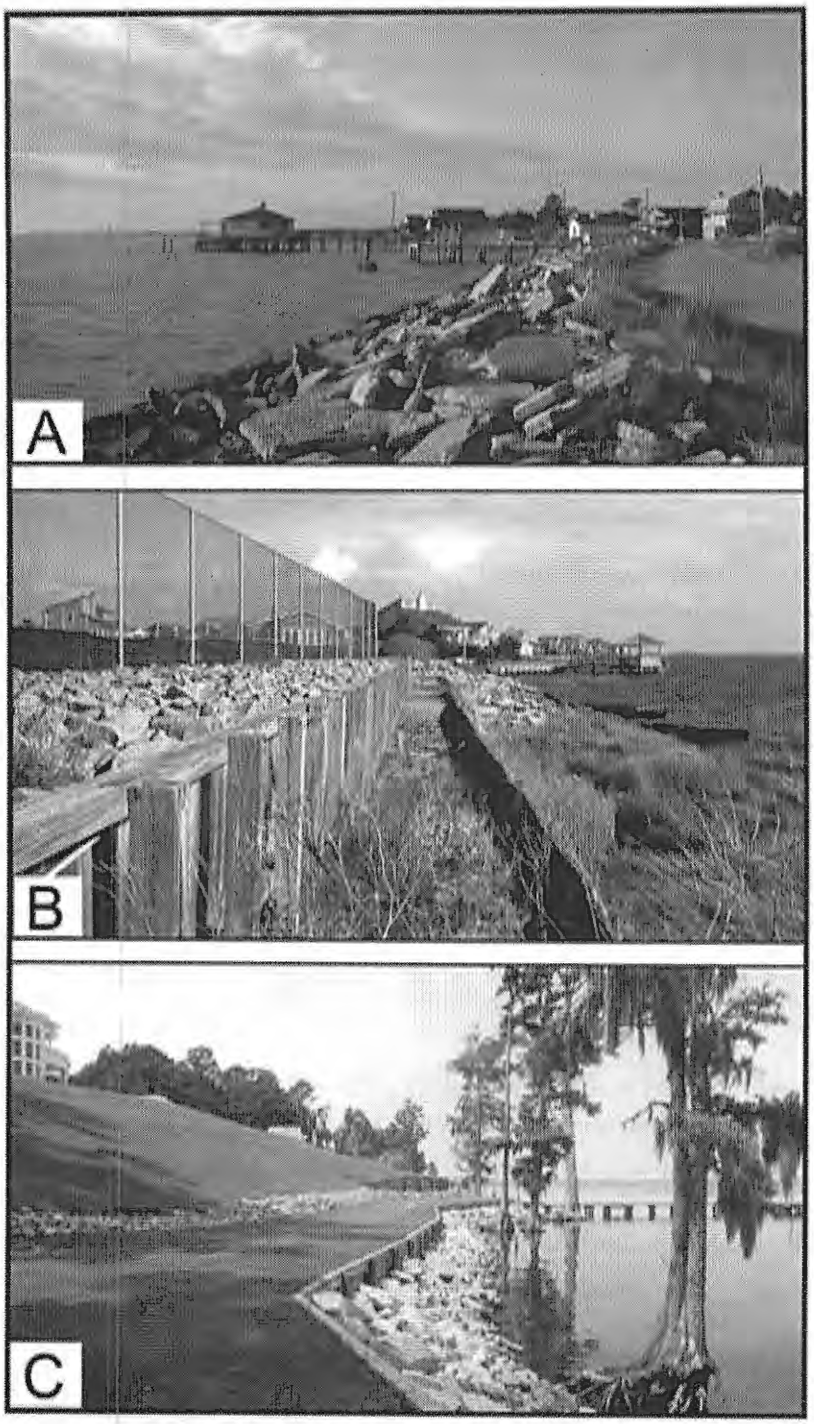


Figure 1-36. Hardened structures along the sediment-bank shorelines within the estuarine system were built in a desperate effort to stabilize the rapidly eroding shoreline. Notice that there are no sand beaches in front of most stabilized estuarine shorelines. Panel A. Concrete rip-rap has been dumped multiple times along Sound Side Road on the back side of the barrier island at Nags Head. Panel B. Multiple layers of wooden groins, wooden bulkheads, and rock revetments have been emplaced to protect the tennis courts on the back side of the barrier island at Nags Head Cove. Panel C. The sediment bluff was terraced; steel bulkheads and rock rip-rap were emplaced along the shoreline at Mauls Point in the Pamlico River estuary. All photographs are by S. Riggs.

Class Assignment:

A. Read the newspaper articles printed in this lesson or other relevant articles that your teacher has collected.

B. Work with your group as directed by your teacher.

C. One group will argue for closure of the inlet and include the following citizen assignments:

- A resident of Hatteras Village with two children who attend school in Buxton on the other side of the inlet
- A local politician who represents the residents of Dare County
- A representative of the Dare County Tourism Bureau
- The owner of a motel in Hatteras Village used by fishermen

D. The second group will argue for leaving the inlet as it is and explore other means to transport people from one side to the other and include the following citizen assignments:

- A coastal geologist
- An environmentalist
- A wildlife manager
- A state representative who is on the budget committee

E. A committee (group 3) who will hear the arguments from both sides and make a recommendation to the Governor (with as many members as you choose). While the advocate groups are working, the committee will read all of the articles and make notes of relevant points that they will use to help make a decision.

F. Groups 1 and 2 may have extra members who will serve as "research assistants" to help the committee find additional information to support their position. You may use sources other than the included articles to support your case.

G. Allow each side to present its points for a set time limit and then have one person summarize for each side.

H. Committee #3 will discuss the pros and cons and prepare a written report to submit to the Governor outlining their recommendation and the reasons for their decision. Although this exercise is a simulation, it will prepare you to advocate in the future for a particular course of action, and it will give you experience in considering all kinds of evidence and a wide range of opinions before you make decisions.

**Reading #1: Basnight Lobbies for Coast (This article is reprinted with permission of *The News & Observer* of Raleigh, North Carolina, 2003)**

By Jerry Allegood, Staff Writer

COINJOCK --As Marc Basnight approaches the high-rise bridge over the Atlantic Intracoastal Waterway in Currituck County, he reaches for his cell phone. "It'll be better reception up here," he explains as his Ford Explorer rises over the lowlands and backwaters that spread out for miles. He checks with his office in Raleigh, returns a call and snaps the phone back in its holder before heading to meet local officials. A call from Basnight..... can get things done.

After 19 years in the [state] Senate, he knows government terrain like he knows the flatlands of Eastern North Carolina where he was born and raised. Officially, he's leader of the Senate; unofficially, he's one of the state's most powerful politicians. The past few days, Basnight, 56, has been in fine form, unabashedly using his political and persuasive powers to speed government aid to northeastern North Carolina after its mugging by Hurricane Isabel. He's not reluctant to call Gov. Mike Easley or top officials of the Federal Emergency Management Agency.

His lobbying has helped focus state and federal assistance to repair N.C. Hwy. 12, the only highway down the Outer Banks, after it was battered by ocean overwash and severed on Hatteras Island. A fleet of yellow state Department of Transportation road graders and trucks hauled sand off the highway soon after the winds died down last week. He had his assistants working with federal agencies on a way to quickly fill in the new inlet near Hatteras Village.

Basnight said he gets personally involved because the beaches and the barrier islands are crucial to the local economy. Not only do tourists spend money, he said, but local residents build, paint, clean and staff beach houses and businesses. "This is a common man's beach," he says of the Outer Banks. "It's not a black-tie beach."

Over the years, Basnight has worn out a few vehicles traveling around to keep tabs on his domain. After Hurricane Dennis washed out a section of N.C. Hwy. 12 north of Buxton in 1999, Basnight drove his Chevy Suburban over the washout to reach the village. He was there before the NC National Guard came in with Humvees. *Business North Carolina* magazine dubbed him "Boss Basnight." The walls of his restaurant, the Lone Cedar Cafe, are adorned with photos of him posing with the powerful and famous: Billy Graham, Dean Smith, Andy Griffith, President Bush and former President Clinton. Still, Basnight is disarmingly folksy at home in the northeastern corner of the state.

During a tour of hurricane-damaged areas Thursday, he started the day by walking through Henry's Beef and Seafood Restaurant in Kill Devil Hills, shaking hands and asking people how they fared in the storm. "Is he a senator?" asked Richard Boyd of Dante, Va. Boyd didn't know the guy in casual shirt, white jeans and sneakers, but he gladly told him about the damage to his beach house in Kill Devil Hills. Others knew.

Restaurant operator Linda Ezzell snapped a photo of Basnight with Kitty Hawk Mayor Bill Harris and David Stick, a local historian and writer. On the way out of Dare County, Basnight noticed floodwater still standing around homes and businesses. He got on the phone to an aide in his office. “Get in touch with DOT," he said. "Tell them please get more pumps in here."

In Elizabeth City, Basnight met with local officials. He put his chief of staff, Rolf Blizzard, on a speaker phone to take down questions. Pasquotank County Manager Randy Keaton was upset with a FEMA decision not to pay for removing storm debris in subdivisions where roads are not part of state or local road systems. "If they (FEMA) cleaned up the Triangle during the ice storm, they sure better clean up this area from this storm," he said. Basnight agreed to look into the policy, which could add millions to the state and local bill for the Isabel cleanup.

In Colerain, a small Bertie County town on the Chowan River, he toured what was left of the Perry-Wynns fish company after it was hit by a wall of water pushed up the river. Nine of 11 buildings on the shoreline were destroyed, and the other two were left in shambles. A week after the hurricane, the shoreline was still littered with a massive pile of barrels that were used for salting fish. The 50-year-old company, which had about 10 employees, was once a major processor for herring caught in the Chowan and nearby waters but in recent years mainly packed herring, jumping mullet and mackerel caught elsewhere. "It's a family business," said co-owner and manager Lee Wynns. "We've just got to sit down and see what everyone feels about it. You derned well know I'd like to put it back."

On the way back to his Manteo home, Basnight said the nine-hour tour through nine counties had helped him better understand what the state needs to do to weather future storms. "The decisions we make will not affect just what it looks like," he said, "but how people feel about it."

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## Reading #2: World Environment News (Reuters News Service 2003), National Geographic News (November 10, 2003).

According to the *World Environment News* (Internet), the repair work on Isabel Inlet took two months and cost $7 million. According to the authors, the expenditure "is evidence of the politically driven haste with which officials rushed to restore a road that many old-timers here believe will wash away again when the next big hurricane hits . . .". The constant cycle of storms and road repair (or in this case inlet filling) has prompted some officials to offer an alternative. Dare County Commissioner Renee Cahoon explained that the response to Isabel was prompted primarily by the need for people to return to their homes. Considering the cost and the fact that the problem of storms is a constant, Commission Cahoon said that a bridge is needed to provide access along this span—without having to rely on a constantly threatened roadway.

Government statistics show that large numbers of U.S. residents continue to move to coastal areas along the Pacific, Atlantic, and the Gulf. From 1970 to 2000, Dare County's population grew 328% compared to 58% for the state as a whole.

Orrin Pilkey, a Duke University geology professor, has strong feelings about issues facing the islands. According to Pilkey, "Very powerful and very wealthy people live along the beaches. The politically correct thing to do is rush in and help these people who have suffered from an act of God." Residents who lost property have a different perspective. As the owners of the Sea Gull Motel in Hatteras viewed the destruction to their business that had been in the family for 50 years, they were not sure that they were "up to building another motel."

Stan Riggs, a coastal geologist at East Carolina University, says that there is ample evidence that more inlets will form along the islands of the Outer Banks, but that government officials have "little patience to listen to his evidence." According to Riggs, "we were told by government officials after the storm they did not need any geological input. All decisions were being made in Raleigh and Washington."

Riggs says that barrier islands are naturally migrating inland and that storms are essential to the process. The storms transport huge amounts of sand from the ocean side to the sound side of the islands. Once the sand is deposited, vegetation colonizes and stabilizes the sand. Riggs says, "We think we can put roads out there like we normally build roads in upland regions, and the minute we put something out there we want to protect it. All of a sudden we are at war with the ocean."

Riggs goes on to say that the estuarine side of the island has been deprived of sand because of the actions to maintain the road and the artificial dune line. The process in turn weakens the islands and makes them more prone to form inlets as storms hit.

An official of the N.C. Department of Transportation conceded that the efforts of DOT "can't ultimately beat nature." Although Isabel Inlet called for immediate action, a task force is considering a long-term solution, including the possibility of a causeway along the sound side of the island. Geologist Pilkey agrees that this kind of approach holds great promise.

# Constructing an Island Profile

Instructions for students:

1. Using a piece of graph paper, determine the horizontal and vertical scales that will allow graphing the data on the horizontal and vertical axes respectively. Label the horizontal and vertical axes in meters. You may choose to tape several pieces of graph paper end-to-end to stretch out your profile diagram.

2. Correctly label the horizontal and vertical axis on each graph sheet. Locate the sound side on the left and progress across the island to the ocean side on the right.

3. The object of the exercise was to measure the height of the island at measured distances along a straight, horizontal line between the sound and ocean. Notice that the change in elevation is added to or subtracted from the previous elevation at each measurement point. As you plot the data, you will see that each measurement is compared to the previous one; higher elevation means you add and lower elevation means you subtract.

4. Plot the data gathered by the Sea-View team at the Avon-Buxton research site (Table 2-1).

5. Label the following features: sound, marsh platform, N.C. Hwy. 12, barrier-dune ridge, erosional scarp, ocean shoreline. Refer to a slide of Figure 2-2 to see some of the features that are labeled on your profile.

Table 2-1. Sea-View data collected using a "stick-and-string" method for the cross-island topographic profile at the Avon-Buxton site. The data are from the sound to the ocean with distinguishing features and plants found at specific locations along the profile. See Figure 2-1 and Fog. 2-2 for the profile location.

| Distance (m) from Sound Shore | Elevation (m) | Distinguishing Features | Plant Community* |
|---|---|---|---|
| 0 | 0 | Shoreline | Marsh grass |
| 5 | 0.2 | Wrack line* | Marsh grass |
| 10 | 0.3 | Wrack line* | Marsh grass |
| 14 | 0.4 | | Marsh grass |
| 24 | 0.6 | | Marsh grass |
| 28 | 0.8 | | Marsh grass |
| 30 | 1 | | Transition zone |
| 35 | 1.2 | | Transition zone |
| 40 | 1.7 | Top of overwash fan | Scrub-shrub |
| 46 | 1.8 | | Scrub-shrub |
| 50 | 1.6 | | Scrub-shrub |
| 55 | 1.6 | Sand road beneath power line | Overwash plain |
| 60 | 1.6 | | Overwash plain |
| 67 | 1.8 | NC Highway 12—west side | |
| 80 | 1.8 | NC Highway 12—east side | |
| 85 | 1.9 | | Overwash plain |
| 87 | 2 | | Overwash plain |
| 90 | 2.5 | Beginning 1st barrier dune ridge | Beach grass |
| 95 | 3.2 | | Beach grass |
| 100 | 3.5 | | Beach grass |
| 105 | 3.8 | | Beach grass |
| 110 | 3.9 | | Beach grass |
| 115 | 4.1 | | Beach grass |
| 120 | 4.3 | | Beach grass |
| 125 | 4 | | Beach grass |
| 128 | 3.5 | | Beach grass |
| 133 | 4 | Beginning 2nd barrier dune ridge | Beach grass |
| 137 | 5 | | Beach grass |
| 140 | 6.1 | | Beach grass |
| 147 | 7 | | Beach grass |
| 150 | 7.2 | | Beach grass |
| 153 | 7 | Top of erosional scarp in dune ridge | |
| 160 | 4 | Storm beach | |
| 165 | 2.9 | Berm crest | |
| 170 | 2.8 | | |
| 175 | 2.8 | | |
| 180 | 2.8 | | |
| 185 | 2.9 | | |
| 190 | 2.8 | | |
| 195 | 2.6 | | |
| 200 | 2.3 | | |
| 205 | 1.9 | Top of high-tide beach | |
| 210 | 1.4 | | |
| 215 | 0.8 | Top of low-tide beach | |
| 220 | 0 | Bottom of low-tide beach | |

* The plant communities listed in Table 2-1 include the following dominant types of vegetation:

- Marsh grass community:
  - Black needle rush, salt marsh cordgrass, salt meadow hay
- Wrack community:
  - Eel grass (dead submerged aquatic grass that gets washed up during storm events)
- Transition zone community:
  - Marsh elder, cotton bush, wax myrtle, marsh glasswort, sea oxeye
- Scrub-shrub community:
  - Juniper, youpon, live oak, sweet bay
- Overwash plain community:
  - Salt meadow hay, prickly pear cactus, sea oxeye, sand spur, Pennywort, broom-straw rush
- Beach grass community:
  - Sea oats, American beach grass, penneywort, sea elder, sea rocket

The data set below (Table 2-2) is from a site on another barrier island off the North Carolina coast. This profile does not cross over the entire island. It just shows a profile of the beach at the site. Work individually to plot the points. Be sure to label your graph correctly.

From the appearance of the graph, what can you say about the topography at this site that is different from the Avon-Buxton site?

Table 2-2

| Distance from shore (meters) | Elevation (centimeters) |
|---|---|
| 0 | 0 |
| 3 | 2.0 |
| 6 | 3.0 |
| 9 | 4.5 |
| 12 | 6.4 |
| 15 | 10.8 |
| 18 | 12.1 |
| 21 | 11.5 |
| 24 | 10.9 |
| 27 | 9.9 |
| 30 | 9.4 |
| 33 | 11.9 |
| 36 | 15.6 |
| 39 | 17.0 |
| 42 | 22.0 |
| 45 | 23.5 |
| 48 | 21.8 |
| 51 | 13.5 |
| 54 | 11.0 |
| 57 | 9.5 |

Constructing a profile of your school yard:

Materials (per group):

-Two pieces of 2" x 2" x 8' wood boards or other similar material
-Ball of heavy string or light rope
-Marker pen
-Measuring tape
-Hanging string level, masonry line level, or sight level
-Graph paper
-Profile data sheet, pencil and erasure

Getting ready:

1. Cut a groove into one of the sticks exactly four feet from the bottom in order to keep the string in place.
2. Using the marker and the measuring tape, place a zero mark at the halfway point on the second stick. Above that measurement, label the centimeters starting from zero to the height of the stick using negative numbers (you will understand why you do this later). Below the four foot "zero" mark count down the pole in positive centimeters.
3. Measure a 3-meter length of string to be tied between the two sticks. One end of the string will be tied into the groove on the first stick, and the other end should be able to slide up and down the second stick. When placed at the "zero" mark, the line should be perfectly level with both sticks placed on a horizontal floor.
4. Demonstrate how to measure change in elevation in class before going outside.

Procedure: Work in groups of four as directed by your teacher—two to hold the sticks upright, one to use the string level, and one to record the data and make observations at each interval.

1. As directed by your teacher, locate your group and equipment a set distance apart from other groups (e.g., every 3 meters). Set the number of measurements to be taken according to the length of the field area and the complexity and amount of relief in the topography to be surveyed. It might help to have all the groups start at a central point and fan out in all directions. If you use this method you will collect data that you can then use to construct a topographic map of your school yard.

2. Place the stick with the groove at the starting position and separate the sticks until the string is taut. Always lead with the marked stick. Slide the string along the second stick until the string is level according to the hanging level. Record the distance on the profile data sheet as 3 meters.

3. The recorder will then write down the number of centimeters the string moved from the zero mark in the column labeled *Change in Elevation*. If the string moved up the stick, then record the measurement as a negative number (as previously marked on the stick). Record as a positive number if the string moved down. If you do not

understand why this works, discuss it with your teacher.

4. Each team member will help make observations for the recorder to write down at each interval. Observations should include changes in vegetation, descriptions of changes in rock or sediment type and grain size from the bottom to the top of the hill, cliff, ditch, creek bank, etc.; weathering and erosion evidence; depositional features; etc.

5. Move the first stick from the starting point and place it in the exact spot of the second stick. Repeat step 3 for each subsequent measurement. At each new point, move the string along the pole until it is level. Record the horizontal distance and change in elevation.

6. Add each change in elevation to the previous number and record this in the ***Total Elevation*** column on the data sheet.

7. When the predetermined number of measurements has been made or the given distance has been covered, your group should create a profile of the assigned area on graph paper, using the same strategy as in the Avon-Buxton Profile assignment. You do not need to know the actual elevation of the starting point in order to begin; just place the starting point strategically on the graph according to the topography of the land. For example, place the first point somewhere in the middle of the page on the far left if you went uphill and downhill equally. Create a scale that will allow the distances to fit on the page. Finally, label and draw any observations that were made on the profile.

8. If you have access to a U.S. Geological Survey topographic map that covers your site, use the map to first locate your site and then determine the general elevation. Use this number to convert your relative measurements to real elevations and use those to plot your topographic profile. Or if a survey was made of your school grounds for the construction or maintenance of major roads, drainages, or a building, etc., there may be an elevation available on the plans.

# Topographic Profile Data Sheet

Name: ______________________ Date: ______________________
Group Members: ______________________ Period: __________
Location: ______________________ Topographic Profile No. ______________________

| Station Number | Distance | Change in Elevation | Total Elevation | Observations |
|---|---|---|---|---|
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Scenario: A research vessel crossed the Atlantic Ocean traveling east along 39°N latitude. The ship had instruments that measured both the distance from the eastern shore of North America and the depth of the ocean at specified intervals. Look at the data provided on the data table below (Table 2-3) and think about how you would set up your graph. Clue: Your starting point (0) is where the land and the sea meet (shoreline). Where should you place this point on your graph to show the change in the sea floor across the Atlantic? Which distances should go on the vertical axis and which on the horizontal? Decide on a scale and label the axes appropriately. Plot the points on your graph paper and connect the points. What features on the ocean floor can you identify on your graph?

Table 2-3

| Distance from North America (km) | Depth (m) |
|---|---|
| 0 | 0 |
| 160 | 165 |
| 200 | 1800 |
| 500 | 3500 |
| 800 | 4600 |
| 1050 | 5450 |
| 1450 | 5100 |
| 1800 | 5300 |
| 2000 | 5600 |
| 2300 | 4750 |
| 2400 | 3500 |
| 2600 | 3100 |
| 3000 | 4300 |
| 3200 | 3900 |
| 3450 | 3400 |
| 3550 | 2100 |
| 3699 | 1330 |
| 3700 | 1275 |
| 3950 | 1000 |
| 4000 | 0 |
| 4100 | 1300 |
| 4350 | 3650 |
| 4500 | 5100 |
| 5000 | 5000 |
| 5300 | 4200 |
| 5450 | 1800 |
| 5500 | 920 |
| 5600 | 180 |
| 5650 | 0 |

Work in your group to complete the assignment below:

1. Read the editorial below (Used with permission of *The Daily Reflector,* Greenville, N.C.)
2. Discuss these questions in your class or in small groups:
   A. After Hurricane Floyd, what position did the Greenville City Council take in regard to development in the flood plain? What was the rationale for that decision? What factors prompted a change in this position in 2004?
   B. What is the position of this editorial?
   C. If you were on the City Council in Greenville, what position would you take in regard to rezoning the property in the flood zone to allow for construction of apartments? What would be your rationale?

### 4/11/04 EDITORIAL: Trouble Rising — Prosperity Means Little if History Repeats

Six weeks ago, a last-minute, out-of-order change to Greenville's comprehensive plan set the stage for land at the intersection of U.S. 264 and Greenville Boulevard to be rezoned.

The City Council sealed that deal last week by approving a request to build 500 apartments on property covered for days by several feet of floodwater during Hurricane Floyd. The decision is the first practical impact of a policy change allowing dwellings in the floodplain of the Tar River. The rezoning came as no surprise. Yet that makes it no easier to accept. A conscientious, sure-footed City Council has ignored history, embracing public policy that places people in harm's way. And in doing so, set a troubling precedent for growth carrying more weight than public safety. Greenville needs no lessons in what happens when you build in flood-prone areas.

In 1999, flooding from Hurricane Floyd covered 58 percent of the land in Pitt County. Six people lost their lives. Hundreds lost their homes. Hundreds more who were stranded by deadly brown water had to be evacuated at great risk to human life.

That disaster laid bare the facts.

In Greenville, hundreds of apartments for students at East Carolina University had been built in the path of floodwaters. So had a public housing project, a large retirement community and trailer parks. An expensive buyout program relocated many of those people. And in 2000, the City Council agreed that no more residential development should take place in the newly drawn floodplain, a deep and sensible bow to nature's humbling lesson.

Now that course has been reversed. Landowners and developers who pushed the change argued that prohibiting dwellings in the floodplain put too much land north of the Tar River, an area that has not shared proportionately in Greenville's prosperity, out of consideration for development.

Yet prosperity will matter little if history repeats itself. Even if dwellings are built above the high-water mark — as the new ordinance requires them to be — floodwater will surround and strand residents in apartment complexes in the same way it did four years ago. The cost of such policy is obvious, both in public dollars and human lives. On both counts, it is the citizens who will pay.

Soon, the foundations of nice, new apartments will appear at the intersection of U.S. 264 and Greenville Boulevard. As they rise, literally, above the lowland, they should serve as a warning of what can happen when public safety takes a back seat and the desire for growth takes the wheel.

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