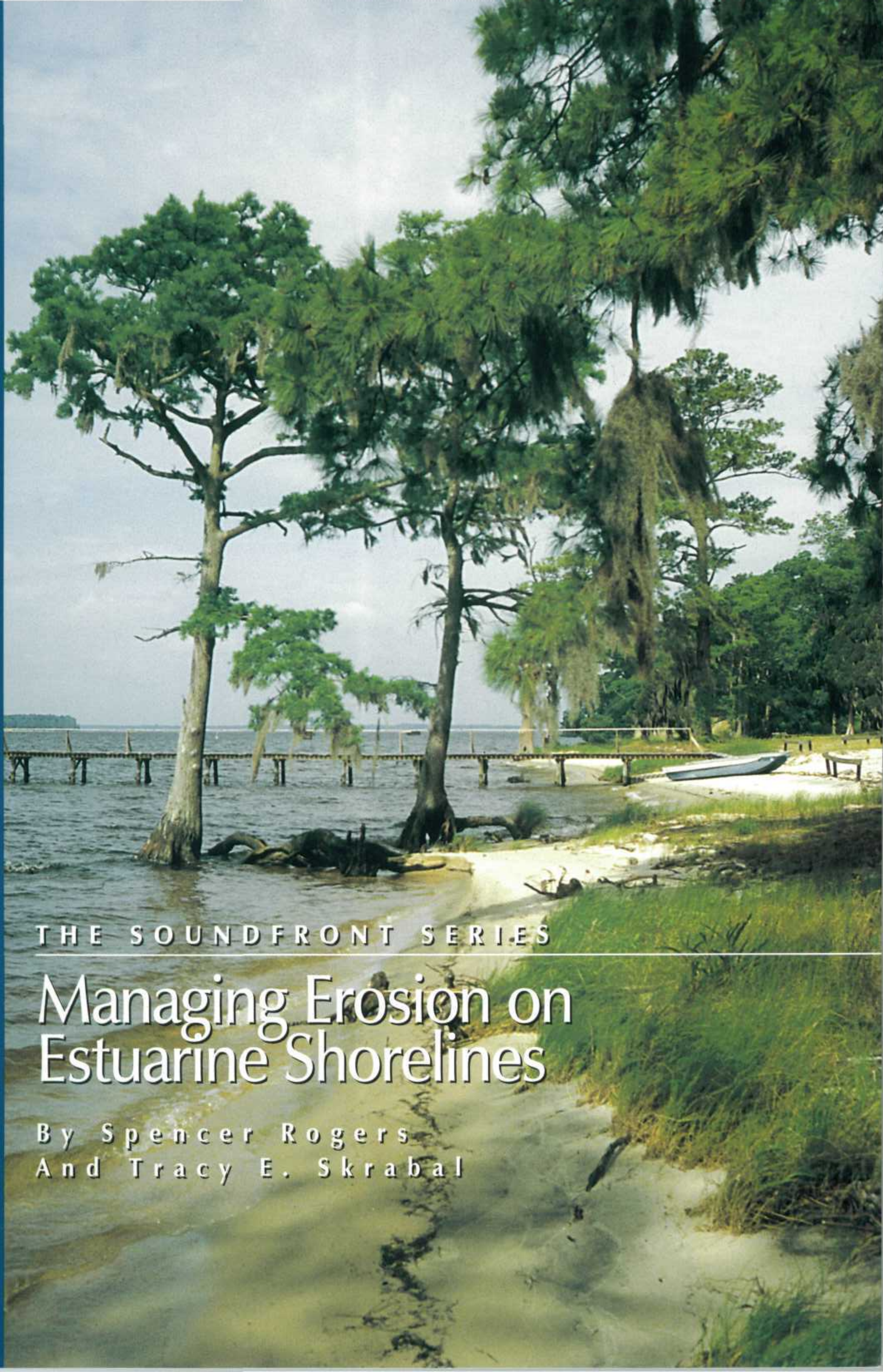
The Soundfront Series



THE SOUNDFRONT SERIES

Managing Erosion on Estuarine Shorelines

By Spencer Rogers
And Tracy E. Skrabal

PREFACE

The estuarine areas of North Carolina are seeing increased residential and commercial development, with more proposals on the horizon. Sustainable use of these areas requires awareness, understanding and implementation of sound design and management options. The long-term environmental health of the land, water and natural resources will benefit the growing economy and quality of life.

The N.C. Division of Coastal Management with North Carolina Sea Grant and the North Carolina State University College of Design developed *The Soundfront Series*, informational guides to assist property owners and community planners and managers. The guides are available in print and on the Web.

The series includes:

• *Shoreline Erosion in North Carolina Estuaries*, by Stanley R. Riggs. UNC-SG-01-11.
Riggs is a distinguished professor of geology at East Carolina University.

• *Managing Erosion on Estuarine Shorelines*, by Spencer Rogers and Tracy E. Skrabal. UNC-SG-01-12.
Rogers is North Carolina Sea Grant's coastal erosion and construction specialist.
Skrabal is a senior scientist with the North Carolina Coastal Federation.

• *Protecting Estuarine Water Quality Through Design*, by Nancy White. UNC-SG-01-13.
White is an associate professor of landscape architecture in the College of Design at North Carolina State University.

• *Protecting the Estuarine Region Through Policy and Management*, by Walter Clark. UNC-SG-01-14.
Clark is North Carolina Sea Grant's coastal law and policy specialist.

Lundie Spence, marine education specialist for North Carolina Sea Grant, and Bill Crowell, senior policy analyst of the Division of Coastal Management, served as coordinators and technical editors for the series. Katie Mosher, Ann Green and Pam Smith, all of the North Carolina Sea Grant communications team, edited the series.

For information on the Division of Coastal Management, call 919/733-2293 or 888-4RCOAST. The division's Web site includes information on permits and regulations, as well as contacts for regional offices. Go to *www.nccoastalmanagement.net*.

For information on North Carolina Sea Grant — and to order individual guides or the complete series — call 919/515-2454. Online, go to *www.ncsu.edu/seagrant*.

TABLE OF CONTENTS

Chapter 1: Introduction

Introduction

North Carolina's estuarine areas include nearly 4,500 miles of estuarine and ocean shorelines, and more than 2.1 million acres of estuaries and coastal rivers. The abundance of bayfront vistas and recreational opportunities is paralleled by the dynamic and changing nature of these regions, often creating conflicts between the increasing demand for shoreline properties and the ongoing erosion processes.

Shoreline erosion is a natural process involving prevailing wind, wave and current conditions. The actual erosion rate within an area may vary within estuarine systems and over time, depending upon individual site conditions and the frequency of storms or other causes of erosion.

North Carolina's estuarine landscapes have changed considerably over centuries. Agricultural areas, residential subdivisions and commercial and industrial facilities have replaced once-forested shorelines. As a result, increased runoff containing sediment and other pollutants has entered the surface waters and groundwater supplies. Natural marsh fringes that once buffered and protected uplands have eroded due to natural and man-made causes, resulting in higher rates of upland erosion and associated water quality concerns.

As the demand for estuarine shoreline property rises, the value also increases. Thus, landowners become concerned about property loss due to erosion and must make decisions regarding whether or not to stabilize waterfront property (Figure 1, next page). These are complex decisions because there are numerous options for shoreline stabilization.

Estuarine property owners and local governments face difficult choices as they strive to select appropriate strategies to control erosion that are cost-effective and environmentally sound.

Managing Erosion on Estuarine Shorelines is part of *The Soundfront Series.* This guidebook provides a basic understanding of the nature and causes of shoreline erosion, and introduces a number of management strategies. This publication is intended to provide general guidance, and not to be considered a construction specifications manual. A landowner may undertake some approaches, while other options should be pursued with the assistance of an experienced professional.

In order to provide practical shoreline management options, this guide focuses on several topics:

- Causes and effects of erosion are discussed briefly in this guidebook to help property owners understand various options. A more comprehensive discussion of erosion is found in the companion North Carolina Sea Grant guide, *Shoreline Erosion in North Carolina Estuaries* by Stanley R. Riggs.
- Basic elements of site evaluation are presented, including parameters for evaluating specific sites.
- A range of stabilization options is presented: wetlands planting options, stone structures and vertical walls. In some cases, property owners may handle the task alone. In others, professional services or guidance are required. Some property owners may choose to live with the conditions.
- An overview of the permit process provides readers contact information for the North Carolina Division of Coastal Management (DCM). Updated regulations are available online or at DCM offices in Raleigh and the coastal region.
- Additional resources will assist landowners in making and implementing erosion-control decisions.

Individual property owners, developers and local officials may have interest in specific segments of estuarine shoreline. This guide will put decisions regarding these specific segments into a larger perspective.

Figure 1.

Chapter 2: Planning for Estuarine Shoreline Stabilization Options

Estuarine property owners often have difficult decisions regarding specific sites with active shoreline erosion. Their options may be influenced by permit and policy decisions made by resource managers who must balance land-use options with the long-term health of the estuarine environment.

The first step in developing a shoreline management strategy is to define goals that benefit the property owner and reduce negative impacts on the natural environment (Figure 2, next page). Once appropriate goals are selected, the property owner should determine the specific nature of the erosion problem, evaluate the existing site condition, and choose one or more options to successfully address the erosion problem and achieve the management goals. Table 1 identifies eight possible goals. Other site-specific goals may depend upon the use, geography or access.

Table 1. Shoreline Management Goals

- Stabilize shorefront lands and structures against erosion.
- Protect and/or enhance property values.
- Provide for human safety.
- Achieve cost-effective solutions.
- Protect water quality by reducing runoff and preserving buffers.
- Preserve, enhance or restore natural wetlands, sandy beaches and other intertidal habitats.
- Protect existing or create new uses such as boating access or swimming.
- Ensure compatibility with adjacent land uses.

In some cases, one goal may be achieved at the expense of another. Priorities may vary within different stretches of shorelines or among neighboring properties. Also, it is difficult to achieve all goals at the lowest cost. For example, the option of wetland plantings is environmentally beneficial and may be relatively inexpensive compared to vertical walls. However, planting a marsh with no structural enhancement is generally recommended only for lower energy areas. In addition, two or more approaches may be considered for a particular site, but evaluation of costs, access for equipment or availability of materials may narrow the options.

Shoreline management decisions are based on a variety of factors, including priorities, goals, cost, site conditions and land use. Information sources include consultants and contractors with experience in the following areas:

- Coastal erosion
- Shoreline management options
- Natural resource protection
- Marine construction
- Permit requirements
- Relative costs for various strategies

In choosing a consultant or contractor, take time to visit completed projects and talk with the property owners to assess their level of satisfaction.

Table 2 provides a spectrum of shoreline

Table 2. Shoreline Management Options

Land Management	*Vegetation*	*Beach Fill or Nourishment*	*Shoreline Hardening*	*Sand Traps*
• Development setbacks	• Planted native marsh grasses, such as cordgrass and black needlerush in intertidal area	• Add sand to an existing natural beach	• Bulkheads	• Groins
• Live with erosion			• Revetments	• Breakwaters
• Managed buffer of mixed shoreline vegetation			• Marsh sills	

Figure 2.

Figure 3. Increased erosion of forested shoreline between the two bulkheaded lots.

management options, generally in order of increasing site modification and intervention in the land/estuary interface. Within each management option, a range of costs and impacts should be considered during the planning process. The options are explained in detail in Chapter 5.

PLANNING CONSIDERATIONS

Determine the specific nature of the erosion problem: Does the property have an eroding beach, marsh or upland? What are the forces causing the erosion? Is the shoreline considered a low-, moderate-, or high-energy site? Is the erosion due to long-term conditions or a single event, such as a major hurricane? Evaluating the nature of the erosion may be limited to one property or may require review of a much more complex length of shoreline.

Identify management goals and set priorities for the site: Use Tables 1 and 2 to begin the assessment. Setting goals for a shoreline project is a critical step in moving forward with any approach. Goals to stabilize land and protect structures may conflict with goals to protect habitat. On the other hand, some projects may be designed to achieve several goals. Once goals are established, property owners may identify more specific priorities and make decisions about what works best for each unique situation.

Consider potential effects and interactions of the project on adjacent properties and the natural environment: Many strategies to protect the property from shoreline erosion can result in increased erosion of adjacent properties (Figure 3). Some options reduce the sediment supply normally feeding a sandy beach or marsh area (Figure 4). A project may cause wave and current energy to be redirected to adjacent unprotected shorelines. Give consideration to the need for, and possibility of, a cooperative project between neighboring properties or within a community. Joint projects may cost significantly less than a piecemeal approach, while avoiding the "domino" effect of unwanted erosion. Measures should be considered to minimize damage to adjacent or nearby properties, and to protect natural estuarine habitats.

Compare costs and availability of materials: Assuming all other factors are equal, costs and material availability may be the deciding factors between two effective options. In addition, property owners should consider the accessibility of the site for materials and equipment, costs of labor and equipment for each approach, site adaptations needed for each measure, and long-term durability and expected lifetime for an erosion-control measure. While costs are always important, a less expensive alternative may not realize the level of benefits that may be achieved from another approach, such as long-term stability, protection and/or enhancement of marshes or beaches, and aesthetic appeal.

Compare complete costs of approaches: For example, compare the cost per linear foot of the structure versus the cost per foot for the overall protection. In some cases, it may be more cost-effective to choose the "no action" alternative over any structural measure. For certain site conditions, property owners may prefer to move structures and infrastructure or retreat from the property rather than to spend money on costly approaches that may be unsuccessful against the existing high-energy forces.

Develop a realistic approach: In evaluating site conditions and design for a shore-protection strategy, keep your expectations realistic. The forces of nature are often unpredictable and dynamic. Both the advantages and relative risks of living along the shoreline should be factored into developing an approach for shoreline management. Structural approaches are generally designed to be effective for moderate storm conditions, and to remain relatively stable for longer periods of normal conditions (although materials may fail in shorter time periods). It may be unrealistic to design for catastrophic weather conditions such as extreme hurricanes, as the structures may be too costly or result in greater adverse impacts for the adjacent properties and natural environment.

Consider permit requirements: Any evaluation should include an assessment of federal, state and local permits needed to implement a given approach. Information regarding application procedures and rules governing approvals should be obtained from the appropriate agencies.

In North Carolina, property owners likely will need a Coastal Area Management Act (CAMA) permit for any development on or near the shoreline. An estuarine project also will need to follow development rules specific to the Area of Environmental Concern (AEC) in which the property is located.

In addition to a CAMA permit, a project may also need other federal, state, and/or local approvals. For current information on permit needs for shoreline erosion-control measures, contact the N.C. Division of Coastal Management. On the Web, go to *www.nccoastalmanagement.net* and follow the links for rules and permits for the *CAMA Guide to Development in Coastal North Carolina*.

Figure 4. Increased erosion of beach and marsh shoreline adjacent to a bulkheaded lot.

Erosion Causes & Effects

Chapter 3: Estuarine Shoreline Erosion Causes and Effects

Estuarine shoreline erosion can be simply defined as the wearing away of shoreline sediments — the loss of land into the estuary. Erosion is a normal geological process, and the rate of shoreline erosion will vary from place to place. However, when a specific shoreline is disappearing, it becomes far more than a geological process for the owners (Figure 5, next page). Erosion may be natural, but it also can become a threatening personal issue. This chapter helps assess the causes and explain the range of erosion on a shoreline segment. Chapter 5 describes a variety of erosion management alternatives. Combined, the guidebook will discuss the generally inevitable tradeoffs that occur when using erosion-management techniques.

EROSION CAUSES

Shoreline erosion in the estuaries is caused by moving water, usually waves or currents. Breaking waves only several inches tall have the power to move sand and other sediments both offshore into deeper water and along the shoreline to someone else's property. Once coastal sediments are in motion, they are often redistributed based on grain size and weight. The finest and lightest sediments, silts and clays, are suspended in the water column and transported to deeper, less turbulent water where they settle to the bottom of bays and sounds. Larger and heavier sediment, such as gravel and boulders, are rare in North Carolina's estuaries. They are too heavy to be moved very far by the small waves of the estuaries. Where present, most of the gravel and boulders remain in place near the shoreline, but may settle as finer sediments are removed from around and under the larger material. Sandy sediment is bounced along the bottom under the waves.

The circular motion of waves causes reversing currents as the wave form passes. First, the current moves in the same direction as the wave. But then it reverses to opposite the wave motion under the wave trough. Thus, waves give sand-size sediment more complex motion patterns. Depending on the shoreline conditions, sand may be moved away from, back to, and along the shoreline — sometimes all at the same time. Once the shoreline sediments are set into motion by the waves, gravity always has the edge, gradually moving sediment of all sizes away from the higher positions along the shoreline to deeper parts of the estuary.

Shoreline erosion also can be caused or increased by boat wakes. Recreational and commercial boats can generate closely spaced, steep waves that are particularly prone to cause erosion. The larger and faster the boat, generally the larger the wave created. On wind-sheltered shorelines, wave heights can still exceed three feet due to boat wakes. This is particularly the case along the Intracoastal Waterway (ICW). The ICW was constructed to provide an inland route, sheltered from ocean waves, for commercial vessels to transit the East and Gulf coasts. In many areas, the waterway was constructed as a straight canal through marshes and even upland property (Figure 6). Prior to construction, the builders obtained a wider easement on both sides of the original canal, anticipating future erosion. Many of these excavations have doubled in width since construction was completed in the mid-1930s.

TIDES AND WEATHER

Changes in water level, due to lunar or wind tides, can affect the shoreline. Higher waters allow larger waves to reach the

Figure 5.

Figure 6. Overhanging peat sediment with marsh grass, probably due to waves and tidal currents.

shoreline rather than break in shallow water offshore. In tidal areas, most erosion of the upland property takes place at high tide rather than low tide (Figures 7,8).

Storms and hurricanes also can drastically alter water levels. Storm surge and sustained winds can cause the water level to rise along some shorelines, while dropping the water level on others. When onshore winds and waves accompany the storm surge, erosion of the shoreline is more likely.

Although often thought to be constant, sea levels are gradually rising on most world shorelines. The rise is measured not just in geologic time but also by tide gauges in place for tens to hundreds of years. In North Carolina, sea-level rise has been estimated to continue in the range of four inches to nearly two feet per century. This seemingly small vertical change would be greatly amplified by the flat slope of the coastal plain.

On any particular shoreline at any particular time, the wave conditions and water levels in the estuaries are determined by the weather, primarily the direction, speed and duration of the wind. Shoreline erosion is most often a weather-driven phenomenon. Like many familiar weather conditions, shoreline erosion can be expected to be highly variable over a period of years or decades. Consider rainfall. North Carolina never seems to have an “average” rainfall year — usually there is a drought or flooding. Likewise, wide variations in erosion should be expected from year to year.

When deciding how to address any erosion on a shoreline segment, consider both the long-term erosion that might occur over the next few decades as well as the potential erosion during an infrequent but severe storm such as a hurricane. The best solution for long-term erosion is often different than the best choice for relatively rare, storm-induced erosion. The apparent threat of erosion is usually perceived by recent losses over a day, a month or a year. Understanding both the long-term, chronic erosion on your shoreline and the effect of any recent severe storms will aid in choosing the best solutions.

Figure 7, top: Low-bank erosion of a forest. Figure 8, bottom: High-bank erosion of a forest. Note the probable high-tide position.

Chapter 4: Site Evaluation

Site Evaluation

Estuarine shoreline erosion will vary by region and by particular features of a given area. Here are six points to consider when evaluating a property site.

1. Remember that historic changes are often the best tool in predicting future erosion. Look for old surveys or photographs that go back at least 10 years. Older is better, preferably 50 to 100 years. A few infrequent storms may not be much of a threat to your property. However, chronic erosion over a long period may require more careful scrutiny. Do not panic over a single storm. One storm may be a rare but severe event, not to be repeated for decades.

2. Orientation of property and land use affect erosion. Property exposed to storms, boat wakes and tidal currents will erode faster, with wetlands having the highest potential, followed by low- and then high-banks topography. Runoff due to buffer removal and/or hard surfaces also removes more sediment from the shoreline, resulting in increased erosion.

3. Beaches provide evidence of sand in motion and, in most cases, erosion. If a beach does not experience relatively frequent rearrangement by waves, plants will take over, converting it to a vegetated upland or fringing wetland with different erosion characteristics. Sandy beaches are often indicators of active bank erosion on the site or somewhere else (Figure 9, next page). Determining the prevailing wave direction provides the general direction of sand movement. In some cases, surface runoff and groundwater seepage can contribute to increased sediment on the sandy beaches.

4. The presence of terrestrial, not wetland, living vegetation, on the shoreline is usually an indicator of a stable upland property. Most plants cannot tolerate either erosion or much burial of the roots. Large trees are evidence of a historically stable location. It is common around higher shorelines to find large trees growing on top of the ridge but only smaller trees of the same species along a lower terrace, adjacent to the shoreline. This is usually evidence of infrequent storm damage. For example, a hurricane or severe storm may erode the high bluff, but the lack of more severe chronic erosion allows new vegetation to become established on the lower terrace.

Healthy terrestrial vegetation can indicate the historical stability of the upland area, but definitely does not always reflect the future of the shoreline. Fallen trees are common shoreline features. Smaller storms erode and remove the grasses and shrubs. Larger trees that collapse from erosion are often too large to be floated in the storms and are left where they fell, clear evidence of recent erosion. Once dead on the shoreline, natural decay processes take over. Most trees will decompose in 10 years or less, depending on the species. Fallen trees on a shoreline indicate erosion over that time period.

Cypress trees — common along the fresher water shorelines — provide evidence of the rate of erosion. Cypress can live offshore in several feet of water. However, cypress seedlings cannot grow in the open water. They must take root on seasonally dry land. If your shoreline has cypress trees growing offshore, they did not start life out there. The shoreline has eroded. The age of the tree can be used to estimate when the shoreline was waterward of the tree.

5. Salt marshes and other shoreline wetlands may have higher rates of erosion than most other shoreline types in the estuaries. Their unique tolerances to saltwater and freshwater inundation as well as their low elevation make their erosion patterns different from upland areas. During hurricanes, wetlands are submerged by the storm surge. Once under water, erosion-causing waves pass over without much effect. (*Later, it is explained how this trait can be used to reduce upland erosion.*) Marshes and wetlands are usually resistant to erosion in the worst storms. In contrast, their low elevation exposes them to more frequent, daily wave conditions. Most marshes and wetlands experience chronic rather than acute erosion. These areas are less sensitive to severe storms.

6. A site's shoreline erosion potential should be put into a larger context. For example, a property owner should consider how specific shoreline management options may change surface water discharge patterns. The management option should not increase runoff.

Figure 9.

Chapter 5: Options for Managing or Controlling Erosion

There are many different types of structures and methods for dealing with estuarine shoreline erosion. These options can be grouped into five broad classes, based on similar functions, such as:

- *Land management*
- *Vegetation*
- *Beach fill or nourishment*
- *Shoreline hardening*
- *Sand traps*

Each option represents a series of complex tradeoffs — property use by the owner, impacts on adjacent shorelines and effects on the environment (Figure 10, next page). Tradeoffs may be described from separate perspectives: the property owner's use of the land, the impact on neighboring shorelines, water quality of the adjacent waters, and the biological impact on the aquatic resources. Different perspectives may lead to different conclusions.

With the exception of beach fill, erosion-control options prevent the eroded upland from sharing sand with neighboring beaches. By altering the sand supply to protect uplands, some adverse impacts on adjacent shorelines are unavoidable. The exact pattern of erosion tradeoffs will depend on many factors. Erosion may be marginally increased on both sides, or one side may experience decreased erosion as the other side erodes faster. This is even true for vegetative alternatives. Minimal impacts typically occur when all of the beach erodes at a slow rate, rather than forcing unprotected shorelines to provide the sand supply for protected areas. The effect is most obvious on beaches with higher waves.

LAND MANAGEMENT

Live with it or plan for erosion.

This option recognizes that shoreline erosion will continue at a rate based on the evaluation of the shoreline history. For new development, land management means advance planning of building locations and other development activities so that these structures will not be threatened or can be readily adjusted during their useful lifetime. Examples include voluntary building setbacks from the shoreline to allow room for future erosion, or a plan for periodic lengthening of the landward end of a dock as the shoreline retreats.

For existing development, the best choice also may be no action to protect the shoreline (Figures 11,18). After evaluating the likely future erosion, it is often cost-effective and feasible to live with it. This choice depends on the rate of erosion. It is easiest to apply where the erosion rates are low. However, it may be impractical where erosion rates are high or where existing structures are already threatened.

From a property owner's perspective, living with erosion is often the lowest-cost alternative since no action is needed. If conditions change, the property owner may still consider use of the other options at any time in the future.

When surprised by the presence of shoreline erosion, property owners often feel financially threatened as their expensive land disappears into the water. In reality, shoreline property is generally valued by location, view and waterfront footage rather than by the total land area, a value commonly applied to inland lots. As long as the existing and future uses of the land are not threatened, the value of the property is seldom harmed by losing a little upland area to erosion. A house 150 feet from the shoreline will have the same value as that house at 100 feet, all else being equal. The property value is more likely to be affected when a building or other man-made feature or a natural amenity, such as a trophy tree, gets close enough to be perceived as threatened. Advance planning can avoid the perception of an erosion threat.

On unprotected, estuarine sandy beach shorelines, allowing erosion to continue may have the lowest impact on neighboring beaches. This is because erosion from the upland areas is the usual source of the sand that replenishes erosion loss from the beach. Also, where beaches exist naturally, the shoreline is likely to maintain at least a narrow beach for suitable recreational uses.

Within land management, biological and water-quality tradeoffs are complex. Erosion

Figure 10.

Figure 11. An estuarine creek with docks but without stabilization.

is a natural process — and natural processes often are perceived as "best management practices" by resource managers. However, from a water quality perspective, the largest volume of pollutant entering our sounds is sediment. The greatest contributor of sediment entering our larger water bodies is shoreline erosion, followed by agricultural and construction runoff. The eroded soils also carry nitrogen and other nutrients that have been linked to harmful algal blooms and other problems. If a reduction in sediment is desirable, then stabilizing a shoreline may be preferable to letting natural erosion occur.

VEGETATION

Where a fringe of salt marsh fronts a shoreline, erosion of upland property is infrequent or nonexistent. Based on this concept, marsh plants have been added in some locations, creating fringing marshes that have successfully controlled erosion for more than 30 years. Fringing marshes protect the upland in two ways. First, the stems of the grasses act like a porous breakwater, gradually dissipating the wave energy before reaching the upland. Second, the best marsh species used for erosion control build a tough root mat surface that can absorb or dissipate the force of breaking waves, stabilizing the soft, underlying soil. The terrace created by the root mat forces the largest waves to break before reaching the upland, thus reducing erosion on the higher ground.

The success of planted marshes depends upon the shoreline exposure to wind, waves and boat wakes. If the shoreline is exposed to less than one mile of fetch — the distance of open water for wind to build the waves — then marsh planting is likely to be successful. In estuarine areas, smooth cordgrass (*Spartina alterniflora*) is preferred, based on growth rate and tough root mat. It grows in salty to brackish waters, preferring at least a little salt. Black needlerush (*Juncus roemerianus*) is the best alternative in fresher waters.

Generally, these plants are finicky about water levels on the shore. Smooth cordgrass prefers a daily tide cycle with both wet and dry periods, generally growing best between the high-water elevation and mid-tide level. It can grow higher or lower but generally does not compete well with high marsh or upland species. Eventually it will die in deeper water. In estuaries dominated by wind tides, the appropriate planting elevations vary but can be determined by observing healthy native marshes nearby. Once planted, the roots spread quickly and trap organic matter to build a tough root mat. The root mat will build in thickness, gradually raising the ground elevation, eventually approaching the mean high-tide elevation.

Black needlerush grows at a slightly higher and narrower elevation range and in fresher water. Smooth cordgrass spreads faster and usually builds a thicker root mat.

Marsh planting is most effective on beaches or man-altered shorelines with fetches under one mile and where boat wakes are not a significant problem. A marsh fringe at least 10 feet wide is necessary for erosion control, but 20 feet or more is preferred.

Planted marshes usually replace eroding beaches (Figure 12). Environmentally desirable features may be created, including productive biological habitat and an additional vegetative buffer, which protects water quality by reducing the impact of upland stormwater runoff. The biggest tradeoff is the loss of any beach for habitat or human recreation. If the marsh is not established continuously along the shoreline, erosion can continue on the unprotected beaches. The most common cause of failure is planting in an area that experiences severe wave conditions. However, the cost is so low that it is often worth a try in areas with marginal exposure to waves. In some cases, two or more planting attempts may be required for the marsh to take hold. Once established, the marsh will gradually spread by rhizomes or underground root runners that emerge as

Figure 12, top: Marsh shoreline with a team planting grass. Figure 13, bottom: Grass sprigs ready for planting.

Figure 14, top: Rows of newly planted marsh grass. Figure 15, bottom: Mature planted marsh grass absorbing waves, thus decreasing erosion on shoreline.

new shoots, eventually covering the range of water depths that it prefers.

Marsh grasses may be purchased from specialized commercial nurseries or transplanted from existing marshes (Figures 13, 14). Property owners can plant marsh grass as a do-it-yourself project. The method has been particularly effective on sites where previous marshes were destroyed by dredging and filling. Where appropriately sited, a planted marsh can be one of the most cost-effective erosion solutions. Planted marshes are generally considered to be one of the most environmentally desirable erosion-control approaches (Figure 15).

Others types of vegetation also may be helpful in managing the shoreline. Saltmeadow hay (*Spartina patens*) is a salt-tolerant marsh grass that helps stabilize the area landward and is better for use in higher elevations than smooth cordgrass or black needlerush. In freshwater areas, mature bald cypress trees (*Taxodium distichum*) offer effective shoreline protection. The wide trunks act as breakwaters, even though sediment may be lost between the trunks. Cypress seedlings must take root above the normal water level in dry soil. They only become offshore breakwaters as the shoreline erodes back. The slow growth rate requires long-term planning and patience for development of erosion management benefits. Erosion may continue landward of the trees but generally at reduced rates compared to nearby beaches without trees.

BEACH FILL OR NOURISHMENT

A beach on an estuarine shoreline is clear evidence that waves are regularly rearranging the sand, preventing the growth of marsh or upland vegetation. Beaches are erosion features. The simplest explanation is that sand is always being lost from the beach system. Waves and storms replace these losses by eroding the upland property.

Beach fill or beach nourishment is the addition of sand to a beach to compensate for expected or realized losses. The added sand does not *cure* beach erosion but can be considered a treatment for the problem. Therefore, most beach fills must be maintained by periodically adding sand. Upland erosion protection is provided if the beach is kept sufficiently wide to break the storm waves before reaching the upland. Beach fills work best where the wave activity is high but the erosion rates are relatively low, thus reducing the volume of added sand, the frequency of maintenance and, therefore, the cost of the method.

Beach fill or beach nourishment has one major advantage over other erosion-control methods. Other erosion-control options have at least some adverse effect on the adjacent shorelines. In contrast, adding sand to the beach benefits the neighboring shorelines, helping to slow their erosion rate.

An important design consideration is locating a clean sand source. Silts and clays should be minimized. Beach fill alone is considered impractical on beaches with very high erosion rates, but may be combined with groins or larger breakwaters to reduce sand losses to acceptable levels. The added sand also serves to partially offset the impact of "sand traps" on adjacent shorelines.

The major tradeoff for beach fill is that it buries aquatic habitat near the shoreline. When substantial beach fill is placed waterward of the high-water line, it is likely to kill most of what is living on the original bottom. Most species living near active beaches can adapt to more gradual sediment changes. When placed in the waves, silts and clays in the fill are quickly removed from the beach and can affect adjacent aquatic bottom habitat, where species may be less tolerant of burial.

Because of its potential environmental impact, state regulations do not generally allow beach fills for the purpose of erosion control on estuarine shorelines where beaches do not exist. However, regulations allow for the placement of sand as fill on some existing estuarine beaches. Where the biological conditions allow, clean sand has also been placed above the high-water line on existing beaches as a source of sand to be redistributed by the waves.

SHORELINE HARDENING

Historically, shoreline hardening has been the most common estuarine erosion-control method in North Carolina (Figure 10). A variety of structures can be used to armor the shoreline and retain the upland soil. Examples include bulkheads, seawalls, retaining walls and sloping stone revetments. Their function is to protect whatever is landward of the structure. On estuarine beaches, the significant tradeoffs are potential erosion-rate increases waterward and adjacent to the structures, often resulting in the loss of the beach. This is because sediment that is trapped behind the structure is no longer available to supply sand to the beach. On beaches where sand moves along the shoreline in predominately one direction over the year, the structures eventually can interrupt the longshore movement of sand. Sand can be trapped on one side of the structure, benefiting one property but creating a sand deficit and loss on the beach on neighboring properties.

Hardening the shoreline landward of an eroding beach almost always will result in the eventual disappearance of the beach. If you decide to harden the shoreline, plan to lose the beach. The severity of the impact and the lifetime of the remaining beach are directly related to the erosion rate and how far waterward the structure extends. The best way to minimize the impact and maximize the lifetime of the remaining beach is to locate the structure as far landward as possible.

The environmental impact of shoreline hardening is affected as much by the placement of fill and grading of areas landward of the structures as by structures themselves. The fill usually kills plants and benthic animals at the site, converting wetland habitats to upland, terrestrial habitat landward of the structures. Beaches and freshwater wetlands are the most common losses.

The tradeoff is an increased aquatic bottom. As the depth waterward of the structure increases, the hard surfaces of the structure become an attractive substrate for the attachment of barnacles, oysters and other organisms. The structure may also provide feeding habitat for estuarine fishes. The biological benefit is directly related to the surface area of the structure in the appropriate water depth. For example, vertical walls have a limited surface area compared to the large irregular surface of stone revetments for potential biological growth and habitat.

The water-quality impact of shoreline hardening is site dependent. Sediment and nutrient losses into the sounds caused by the shoreline erosion will be reduced. On some sites, stormwater runoff may be better managed with structures than without. Hardening the shoreline, filling and grading will alter the vegetated buffers around the sound that have been shown to effectively remove a variety of nutrients and other pollutants before they reach the sounds. Compared to the original shoreline, the water-quality buffering capacity will depend on the plant species that are replanted landward of the new structure. The most effective water quality buffers include a mix of shallow-rooted grasses for surface runoff and deep-rooted trees for groundwater

Figure 16, top: Rock sills and graded shoreline, ready for vegetative planting. Figure 17, bottom: Completed rock sills with healthy marsh grass sheltered from waves.

flowing toward the estuary. The removal of a naturally vegetated shoreline buffer will alter the original functions of wildlife habitat, nutrient removal and shading. Thus, the new functions of the buffer will depend on the species that are replanted landward of the new structure.

Sills with Marshes and Wetland Revetments

Although marshes have been shown to protect the upland, they can have high erosion rates in areas where heavy boat traffic causes wakes. Most shorelines experience the worst erosion during severe storms. In contrast, the erosion threat to marshes is primarily due to daily wave conditions that remove sediment under the root mat. Once undermined, the root mat breaks off, and the marsh shoreline erodes until the marsh is destroyed. Many present estuarine beaches once had fringing marshes that have now disappeared. As the marsh narrows and is eventually lost, erosion of the upland property usually follows.

Low-elevation stone or wooden structures called sills or breakwaters can be used to successfully plant new marshes in fetches of 10 or more miles and in areas with serious boat-wake problems, such as along the ICW. Sills provide a wave-sheltered area that makes it easier for new plantings to become initially established (Figures 16,17). Sills are typically constructed offshore of unvegetative areas where additional marsh can be encouraged to grow or a few feet seaward of existing marshes. Wetland revetments are usually stone structures placed immediately adjacent to an eroding marsh root mat or other wetland features.

In the long term, structures are intended to protect the waterward edge of the developing root mat from undermining during daily conditions. The structures are kept low in elevation, no more than six inches to a foot above the normal high water level. The low height allows large storm-induced waves to pass over, and it also reduces the original construction cost.

Sills can be used to plant marshes where they could not otherwise thrive or to protect existing marshes that are actively eroding. Obvious undermining of the waterward edge of the root mat can serve as a good indicator of erosion activities in existing marshes. If existing marshes are sufficiently wide and the upland is not eroding, it may not be necessary to plant additional marsh grasses. Marsh widths of 20 feet or greater are preferred for upland protection. Wetland revetments also can be used to protect existing marshes or, in fresher waters, may be used to protect swamp forest fringes or other wetlands that protect the upland but have moderate erosion rates on the shoreline fringe.

Wooden sills are usually the lowest-cost structural approach used to extend marsh protection to more exposed shore-lines. Stone sills are more expensive to construct but can be expected to last longer and to be easier to repair. Both types of structures are too small to provide erosion protection for the upland and are not effective until the marsh grasses are successfully established.

Stone sills and wetland revetments are most often constructed of granite, marine limestone, or concrete riprap. Granite is preferable due to its relative density, angular shapes and availability in a wide range of sizes. Marine limestone has a lower density or lighter weight than granite, making it less stable than granite for a comparable structure. The cost of granite is generally higher than for limestone, but this is often offset by long-term stability and effective-ness. Concrete riprap has similar density as granite but is usually produced in smaller, less stable sizes from demolished concrete slabs and other building debris. In most cases, stone sills are constructed to maintain a stable slope of 2:1 or 1.5:1.

Both stone and wooden sills cause waves to break on their crest, trapping water behind the structure. It is necessary to allow the trapped water to return to open water without causing excessive localized currents around the structures. Therefore, sills are designed to be porous. Return flow occurs either between the stones or through half-inch spaces between each sheathing board in the wooden structures. The ends of the structures are left open to allow additional return flow and to avoid trapping larger fish during tidal changes.

The most common construction problems are undersized stone sills that are too steep and have unstable foundations. Stability can be increased by initially placing the stone on a layer of filter fabric to reduce settling. Wooden structures must be well imbedded in the bottom and stiff, or the structure's oscillations when hit by waves will create a scour hole on both sides of the structure, potentially leading to structural failure.

The benefits and tradeoffs when sills or revetments are combined with planted marshes are similar to planted marshes alone. The structures cover additional aquatic bottom but add hard substrate in addition to the marsh habitat. Stone sills cover a larger area of aquatic bottom, but the many nooks add a large surface area that serves as aquatic habitat. Wooden sills offer a smaller area of hard substrate but a smaller footprint disrupting the original bottom.

In addition to losing the beach, the use of marsh for erosion control also requires habitat trading and loss of aquatic bottom for wetland additions. Like other erosion-control structures, successful marsh plantings on beaches can prevent the sand that would have been eroded from being shared with the adjacent shorelines, causing an increase in the adjacent erosion. Given the multiple advantages of planted marshes, the tradeoffs are usually considered to be acceptable. See Sea Grant's *Shoreline Erosion Control Using Marsh Vegetation and Low-Cost Structures*, UNC-SG-92-12.

Vertical Walls

Traditionally, the most commonly used erosion-control structures in North Carolina have been vertical walls, variously called bulkheads, seawalls or retaining walls. The function of the structure is to retain the soil behind it during storm waves. As long as the soil or backfill is retained in contact with the landward side of the structure, wave forces applied to the wall are transferred to the earth, requiring only minimal design capacity for landward-directed forces like waves (Figure 18).

The design of vertical walls is dictated not by waves but by the need to retain the weight of the soil and any additional groundwater trapped landward of the structure (Figure 19). The walls must be imbedded sufficiently deep to prevent the toe of the structure from being pushed waterward when eroded by waves. The tops of walls are usually anchored farther landward in the soil to prevent the structure from being pushed waterward by the weight of the soil. Rods or cables attached to the top of the wall, called tiebacks, extend 10 to 20 feet landward of the wall where they are anchored to heavy masses or imbedded pilings called deadmen. The deadmen must be far enough landward to avoid the area that will shift if the wall moves waterward.

Retaining the fill behind the wall is critical to successfully transferring the wave forces. Since the walls are designed to hold up the weight of the soil rather than to resist the waves, even small losses of backfill can

Figure 18, top: Vertical wooden bulkhead retaining weight of soil landward. Note lack of any fringing marshes and scour areas. Figure 19, bottom: Vertical wooden bulkhead in front of housing units.

lead to an initial local collapse, followed by a rapid progressive failure of the entire structure. Preventing the soil from being lost through cracks, joints or other small holes is therefore a critical design issue. Filter fabrics are usually placed on the landward side of the walls to better retain the fill. Because the weight of the retained soil controls the forces on the wall, taller walls require stronger materials and cost more to build properly. Any groundwater trapped behind the wall adds to the weight of the soil against the structure.

Vertical walls can cause adverse environmental impacts. These impacts can include loss of intertidal habitat and increased erosion adjacent to and in front of the vertical walls. These impacts vary with alignment, wave environment, bottom substrate, degree of stormwater runoff, amount of vegetative buffer on the landward side of wall, and the existing marsh in front of the wall. For example, if a vertical wall is placed in an environment of a long fetch and high wave energy, it can be a factor in the loss of marsh vegetation and sediment.

Good design includes provisions to allow water to flow through the wall rather than to be retained. Filter fabric landward of the wall also allows the water to drain, at the same time retaining the soil behind the structure. Sand is preferred for backfill because it drains better than clays and silts that tend to trap the water — adding weight to the retained soil.

The narrow footprints of vertical walls allow them to be moved farther landward than other shoreline hardening structures in the most common applications. A more landward location minimizes the potential environmental impact of any structure. An exception is along high banks and bluffs where room may be needed waterward of the bluff to install tiebacks and deadmen.

Common design problems include failure to plan for future long-term erosion and the localized scour that occurs near the toe of the wall due to wave turbulence. Due to the impact of waves, the vertical face of the wall causes a localized scour near the foot of the wall. The effect of high turbulence caused as a wave breaks, or is reflected, is limited to within a few feet of the wall. Although sometimes temporary, the added scour is a common contributor to storm damage to the structure.

The materials and depth of embedment of any wall have a fixed limit of exposure to waves and scour. Beyond that limit, the wall will collapse due to one of several stresses. Temporary stress often pushes the structure beyond its threshold for failure. Another common problem is not extending the filter fabric deep enough on the landward side of the wall. If erosion on the waterward side drops below the fabric backfill, losses can lead to major wave damage or a total collapse. For more information on how vertical walls function, see Sea Grant's *A Homeowner's Guide to Estuarine Bulkheads*, UNC-SG-81-11.

Materials in use for vertical walls include preservative-treated lumber, reinforced precast concrete panels, and interlocking sheetpiles in steel, aluminum, vinyl or plastic. Each material has its own advantages and disadvantages. Preservative-treated lumber is cost-effective and widely available, but improper lumber specifications have led to early failures when marine borers, such as shipworms or gribbles, attack exposed heartwood, which is too dense for the preservatives to penetrate.

The most common type of wood currently used in constructing shoreline stabilization structures is treated with chromated copper arsenate (CCA), as a preservative. The American Wood Preservers Association (AWPA) annually publishes its *Book of Standards* that lists the proper specifications for marine construction. To find the standards, visit the AWPA Web site: *www.awpa.com/publications.htm* as well as the American Wood Preservers Institute (AWPI) Web site: *www.awpi.com*.

Research has shown that there are adverse environmental impacts associated with leaching of CCA chemicals. Therefore, residential uses of CCA pressure-treated lumber will be phased out by Dec. 31, 2002. It not yet clear how this phaseout will affect CCA pressure-treated lumber used for bulkheads and other marine uses. Alternatives are currently being researched. Please check with your local DCM representative, contractor or local extension agent for the latest findings. Be sure to discuss the pros and cons of using any of these materials with your contractor.

Concrete seawalls are most likely to suffer from insufficient thickness or poor quality concrete, inadequately protecting the reinforcing steel from rusting. As steel oxidizes to form rust, it expands, cracking the concrete from the inside. This can result in severe losses in steel strength and eventual failure of the structure. Since at least three inches of concrete is recommended to protect the steel from salt water, concrete is more cost-effective for larger walls and commercial installations.

Interlocking sheetpiles have been in commercial use for many years in steel and aluminum. Corrosion is one of their biggest threats. Vinyl or plastic interlocking sheetpiles recently have become more available. Materials include PVC used in plastic piping and fiberglass used in boat construction. As is common with new products, improper design and installation have been a frequent problem. PVC is more flexible than most other materials and can require more bracing and tiebacks than contractors anticipate. In its raw form, PVC is susceptible to damage from sunlight and should include protective additives when formulated for sheetpiles.

Sloping Revetments

Revetments harden the upland area with a sloping surface designed to break waves more gradually than vertical walls. Revetments are better wave barriers and cause less temporary, local toe scour than vertical walls. Upland protection is provided by the heavy mass, wave-breaking ability and soil-retaining capacity. However, the installation of revetments may be more difficult than for vertical walls. More attention is required to prevent backfill losses through the structures. Also, the need for a sloping surface requires a wider footprint for revetments, and thus they must extend farther waterward than vertical walls (Figure 20). An exception is on high banks and bluffs where a revetment may be constructed at the face of the bluff, but a vertical wall would need to be 15 to 20 feet farther waterward to allow room for tiebacks and deadmen. In this case, the resulting waterward extent of both types of structures is about the same distance from the bank.

Stone is the most common construction material for revetments (Figure 21). Revetments are constructed by placing stone in a triangular cross section (Figure 20). The ability of the structure to remain stable in the waves is determined by the size of the stone, the density of the stone, the number of layers of stone and the slope of the revetment surface. Larger and heavier stones and/or flatter slopes are necessary for larger waves.

In coastal North Carolina, three stone materials in common use are granite, concrete riprap and marine limestone. Quarried granite and concrete riprap from demolished structures have similar density or weight per cubic foot and may behave about the same in waves. Marine limestone,

Figure 20, top: Preparation for a sloping rock revetment in construction phase. Figure 21, bottom: Marine limestone used in sloping rock revetment.

identified by the multitude of marine fossils on its surface, is a lighter, softer stone available from quarries close to the North Carolina coast. Transportation distance is a major consideration in the cost of stone structures.

For any size and density of stone, the flatter the slope of the revetment, the more stable the stone. Successful slopes are commonly 2.0 to 1.5 feet for each foot in vertical rise.

The most frequent design and construction problem for revetments is undersized stone. Design guidelines developed by the U.S. Army Corps of Engineers predict that a revetment with two layers of 120-pound stone on a 2:1 slope begins to become unstable when wave heights exceed 2 feet. That is a relatively low wave height for wider estuaries and boat channels. A revetment constructed with stones small enough to be picked up by hand is likely to be unstable in all but the most sheltered bodies of water and no-wake zones. Heavy equipment is needed for proper construction of most stone revetments.

Another common problem, also found with vertical walls, is inadequate attention to foundation details and provisions to tolerate continued erosion waterward of the structure. Proper design features may include:

- Excavating the base of the revetment below the existing grade to tolerate future erosion farther seaward;
- Using filter fabric or layers of smaller stone under and landward of the armor stone to reduce settling; and
- Designing toes to settle in order to protect the landward sections of the structure.

Revetments also may be constructed with solid surfaces of poured-in-place or fabric-formed concrete. A variety of interlocking precast concrete armor plates also is available. These types of revetments are not as effective at breaking waves as the more irregular stone surfaces. The solid sloping structures are less effective at retaining the landward soil, requiring more care in design and construction. Thin-layered concrete revetments are particularly prone to loss of backfill and, like vertical walls, tend to require full replacement when moderately damaged. On the other hand,

Figure 22. Gabions, showing the wire box to hold the rocks, in a sill-type configuation.

stone revetments with moderate to severe damage are relatively easy to repair by adding more stone.

Gabions

Gabions are wire cages filled with smaller stones, which function much like revetments (Figure 22). The cages retain the stone, allowing it to function as a much heavier unit in larger waves. Gabions are available in different shapes and may be stacked to form vertical walls or sloping revetments. Even when placed as a vertical wall, the porous units behave like a revetment by reducing localized scour at the base of the structure. Corrosion of the wire baskets is a common problem in salt water, even when galvanized and/or plastic coated. The wire containers are relatively expensive but may be cost-effective where small stone is readily available and larger stone is expensive. Labor cost may become a factor if the baskets are filled by hand or heavy equipment.

SAND TRAPS

Sand traps are used on beaches to collect sand that is regularly being transported along the shoreline by breaking waves. The most common sand traps used in North Carolina are groins and breakwaters. If they effectively trap sand, they also must affect the movement of sand on the adjacent shorelines.

Groins

Groins are typically constructed perpendicular to the shoreline (Figure 23). When used to protect navigation channels, these structures are usually longer and called jetties. Along shorelines, the direction of sand movement depends on wind direction and the angle of wave approach. On shorelines where sand moves predominantly

Figure 23, top: A groin field, showing a series of small, wooden groins on a soundside shoreline. Note the crescent sediment design. Figure 24, bottom: An offshore rock breakwater, which has a mature sand connection or tombolo to the shoreline. Groin field in the background.

in one direction over the year, groins trap sand on one side, acting as a dam. Thus, the shoreline alignment relative to the wave direction is altered, allowing less sand to be moved. If successful, the direct tradeoff is that the trapped sand is prevented from reaching the adjacent beach. The up-current beach benefits from less erosion, at the expense of increased erosion on the down-current segment.

Constructed from wood or stone, groins protect the upland areas by creating or preserving a wide beach to break the storm waves. The best designs are relatively low, only slightly higher than the elevation of the beach. To be effective, a groin should extend across the active surf zone, where most of the sand is moving, and also extend well landward to prevent the landward end from being flanked by waves. Multiple groins are combined to form groin fields, spaced along the shoreline such that the downdrift groin traps enough sand to offset the sand deficit created by the next groin updrift. The more sand these groin fields trap in combination, the larger the sand deficit created downdrift of the last groin.

The tradeoff of keeping sand from reaching the adjacent shoreline can be turned into a benefit where excess sand is a problem. For instance, where sand is lost into a creek or excavated channel, additional sand may be undesirable for water quality or navigation impacts.

Offshore Breakwaters

Offshore breakwaters are constructed parallel to beaches to protect part of the beach from all but the most extreme storm waves. Breakwaters create a highly efficient trap for sand moving in either direction along the beach. Most designs plan for the accumulation of sand from the original shoreline waterward to the center of the landward side of the breakwater, forming a shoreline feature called a tombolo (Figures 24, 25). Both the large structure and the wider beach provide protection of the upland.

A segmented breakwater is formed by a series of breakwaters separated by unprotected gaps. The adjacent structures can be designed to stabilize enough sand in the gaps to maintain a beach wide enough to protect the upland from storm waves. A

Figure 25. Over time, marsh plants will grow on the sand tombolo behind the breakwater structure.

scalloped shoreline is formed. The eventual shape of the stable beach is determined by a complex interaction of the length of the segments, the size of the gaps between breakwaters, the distance offshore, the wave climate and available sand supply.

Much like sills and revetments, offshore breakwaters are usually constructed with sloping stone. Positioned in deeper water, they are subject to larger waves. As with sills and stone revetments, selecting the proper stone size, slope and cross section can be critical to a breakwater functioning properly. The design of offshore breakwaters is best left to professional designers who could consider navigation issues, etc.

Offshore breakwaters can maintain a sand beach indefinitely without regular additions of sand through beach fills. However, typical breakwaters do not provide as much upland protection during extreme storms as do well-designed walls or revetments on the original shoreline. Even when breakwaters are segmented with wide gaps, they are usually more expensive than other options because a larger volume of stone is required than for a revetment on the shoreline. Also, building the structure in the water is more expensive than building on land.

Usually constructed in open water using stone, breakwaters pose environmental tradeoffs, including the loss of aquatic bottom under the structure. But the placement also results in a large increase in the hard substrate for attachment of species like barnacles and oysters and creates a foraging area for fish. Aquatic bottom will be lost as sand is gradually trapped along the protected beach and immediately if combined with a beach fill.

Regulations & Permits

Chapter 6: Regulations and Permits

State and federal permits must be obtained prior to starting constructing of erosion-control structures (Figure 26, facing page). The local government may also require a separate building permit. In coastal North Carolina, a single application through the N.C. Division of Coastal Management (DCM) is required for all state and federal permits. DCM has made a substantial effort to streamline the processing time and complexity of permit applications for routinely permitted erosion-control structures. The application and review process is designed for property owners or contractors who request the most common permits. A permit consultant or professional designer is not required for most applications but may be sought to ensure proper design and construction of certain stabilization measures.

Exemptions and general permits are available for many of the frequently permitted erosion-control options. Proposed designs meeting the conditions outlined in the exemptions and general permits often can be issued in a few days. These permits are sometimes handled through the local government staff. DCM staff is available to describe the type of permit and processing required, and where necessary make a pre-application visit to your site. More complex projects or some infrequently requested structures may require several months for review by state and federal agencies. Planning is necessary to obtain permits if a common exemption or general permit is not available for the erosion-control structure desired.

Most permit reviews evaluate only the environmental impacts of the proposed work. They do not necessarily evaluate the effectiveness of the proposed erosion-control plan or the engineering design. A permit does not mean the erosion-control solution is guaranteed or even expected to work as intended. It is the property owner's responsibility to ensure the option is properly designed to function as expected. Given the cost of some stabilization options, hiring a professional designer may be worth the added cost.

For current information on permit requirements for shoreline erosion-control measures, contact DCM at 919/733-2293 or 888/4RCOAST. Online go to *www.nccoastalmanagement.net* and follow the links to the rules and permits section.

Figure 26.

Chapter 7: Resources

Landowners and resource managers may want to review additional resources before making — and implementing — decisions regarding estuarine shoreline erosion control.

To contact the N.C. Division of Coastal Management, call 919/733-2293 or 888/4RCOAST. The division's Web site includes information on permits and regulations, as well as contacts for regional offices. Online, go to www.nccoastalmanagement.net *and follow the various links.*

The North Carolina Sea Grant site on the Web is www.ncsu.edu/seagrant*. To order Sea Grant publications, call 919/515-9101 or follow the publications links online. Sea Grant coastal construction and erosion specialist Spencer Rogers is in the Wilmington office, 910/962-2491,* rogerssp@uncwil.edu*.*

To contact the N.C. Coastal Federation, call 800/232-6210 or visit the Web: www.nccoast.org*. Senior scientist Tracy E. Skrabal is in the Wilmington office, 910/790-3275,* tracys@nccoast.org*.*

References Include:

- ***American Wood Preservers Association***, *Book of Standards* found on this Web site: *www.awpa.com/publications.htm*

- ***CAMA Guide to Development in North Carolina***, visit *www.nccoastalmanagement.net* and follow the links to rules and regulations.

- ***Erosion Control: Non-structural Alternatives - A Shorefront Property Owner's Guide.*** 2000. North Carolina Coastal Federation. NCCF, 3609 Hwy. 24 (Ocean) Newport, NC 28570.

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- ***A Homeowner's Guide to Estuarine Bulkheads.*** Rogers, Spencer M., North Carolina Sea Grant, UNC-SG-81-11.

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- ***Shoreline Management in Chesapeake Bay.*** 1999. Hardaway, C. Scott and Byrne, Robert J. Virginia Sea Grant, VSG-9911. Virginia Institute of Marine Science, P.O. Box 1346, Gloucester Point, VA 23062.

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