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ESTUARINE SHORELINE DEVELOPMENT HANDBOOK

Environmental Erosion Control and Rehabilitation Guidelines

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Final Report

ESTUARINE SHORELINE DEVELOPMENT HANDBOOK

Environmental Erosion Control and Rehabilitation Guidelines

Prepared by

U.S. Environmental Protection Agency

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CONTENTS

TABLES

FIGURES

1.0 INTRODUCTION

PURPOSE

The "Estuarine Shoreline Development Handbook" provides guidance to individuals, developers, and regulatory agencies who are involved with shoreline erosion control measures, water access construction, and shoreline rehabilitation in estuaries or similar semi-protected coastal waters. It presents an overview of the environmental effects of shoreline development on estuaries, shoreline development design considerations, and a variety of shoreline development alternatives. The various shoreline development alternatives are then discussed in more detail, outlining their effectiveness in various situations, their environmental effects, and other considerations.

This handbook does not provide complete detailed design or construction procedures for shoreline development structures. Supplemental information can be found in the sources listed in the appendix entitled "Additional Information." Similarly, a complete discussion of environmental considerations of estuarine development is beyond the scope of this handbook, and additional sources of information in this area are also included in the appendix.

The handbook presents guidelines for coastal estuarine construction which will minimize environmental effects to the maximum extent practical. It should be recognized that all coastal development will have impacts on the estuary. Some areas may be so sensitive that no development should be allowed. When coastal development or construction is allowed, the best practices available should be followed to minimize impacts. By following the guidelines outlined in this handbook, shoreline erosion control measures and water access construction can have minimal effects on estuarine water quality.

IMPORTANCE OF ESTUARIES TO THE ENVIRONMENT

The importance of estuaries and coastal wetlands is generally well recognized and publicized. Estuaries support a large and valuable recreation industry, provide extensive waterfowl and wildlife habitat, and play an essential role in coastal fisheries. It has been estimated that 31 commercial species of fish and shellfish, accounting for 88% of the total fishery landings of the Southeastern United States, are directly dependent on estuaries. In addition, many other non-commercial species support recreational fishing which provides pleasure for millions of people, as well as millions of dollars to local economies.

Estuaries support some of the most biologically productive ecological systems on earth. It has been estimated that estuarine salt marshes produce up to 11,500 pounds of vegetation per acre per year. That is over twice the average production per acre of wheat, corn, or rice worldwide, and equals the most efficient of farms using extensive fertilization, pesticides and herbicides. It is this productivity that supports the vast fisheries, waterfowl, and wildlife within the estuaries.

Estuaries are under increasing pressure as the population in surrounding areas increase. The number of inhabitants in coastal areas is increasing far faster than in other parts of the nation. By the year 2000, it is estimated that 70 percent of the nation's population will reside in coastal regions. As this coastal migration occurs, so will the demands on the limited resources of the estuaries.

CUMULATIVE EFFECTS OF SHORELINE DEVELOPMENT

The majority of estuarine shoreline development projects proposed consist of minor construction: typically a few hundred feet of shoreline might be involved, with only minor filling or dredging to regrade the shoreline or eliminate shoreline erosion. The effect of such a project might be considered minor by the property owner or developer who does not understand the level of scrutiny the small project must undergo before a permit is issued. However, the impact of shoreline development for a single project must consider the cumulative effect of all such development on the environment of the estuary. The impact of a single project may indeed be minor: the impact of hundreds of such projects in an estuary may have a major effect on the ecology of the estuary.

As an example, the Sarasota Bay, Florida, National Estuary Program has established that the bay's natural habitats have been directly and adversely affected by dredging, filling, and hardening of shorelines. Over the past 40 years, development has reduced the amount of native shoreline still in its natural state to only 22%. Of the developed shoreline, 45% is fronted with bulkheads, 10% surrounded by riprap and 23% artificially filled. As the cumulative result of numerous small shoreline development projects, almost 80% of intertidal habitat has been lost in Sarasota Bay. This has resulted in drastic reductions in fishery productivity. Considerable effort is now taking place to enhance the shoreline habitat through the use of artificial structures and by returning the shoreline to a more natural state.

The sequence of effects between disturbance to the shoreline and impact to the estuarine environment is often subtle and complex. The impact of many separate disturbances may be minimal, while a single disturbance may cause a profusion of effects. The purpose of this handbook is to provide guidance for minimizing the impacts of individual shoreline development projects, which will help to minimize the cumulative effects on the estuarine environment. An example of shoreline development project that has been performed with consideration for environmental impacts is shown in Figure 1.

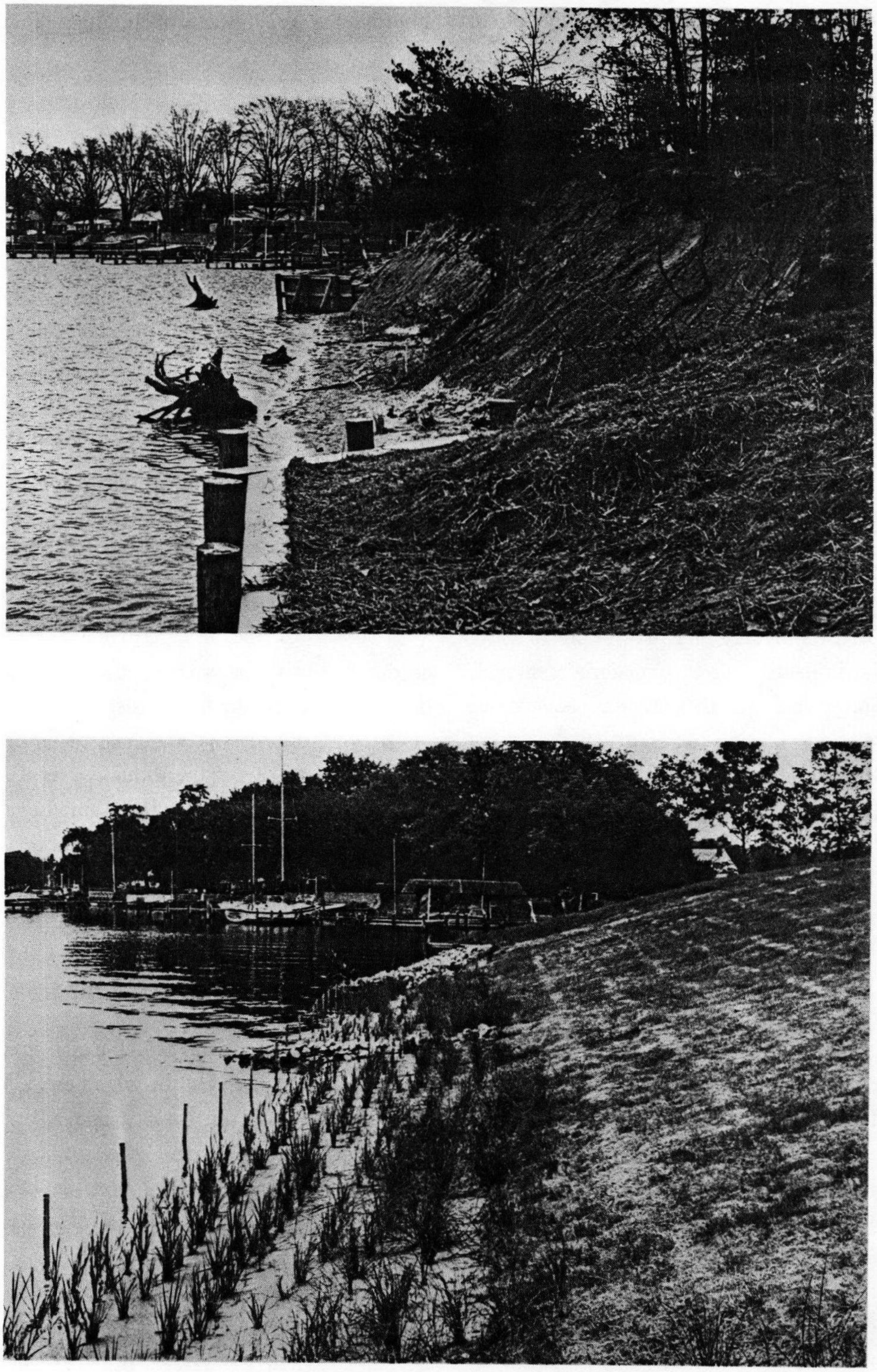

Figure 1. Shoreline Development Before and After Vegetative Erosion Control

2.0 ENVIRONMENTAL EFFECTS OF ESTUARINE SHORELINE DEVELOPMENT

Shoreline development can affect the estuary in a variety of ways: some direct, such as dredging or filling, others indirect such as increasing the runoff from driveways and lawns or increasing the human use of an area due to improved access. Some of the major impacts of shoreline development are discussed below.

FILLING OF HABITAT

Filling of estuarine habitat behind bulkheads directly impacts the environment by eliminating estuarine acreage, but perhaps more importantly by converting ecologically important shoreline habitat supporting a wide diversity of plant and animal life to relatively sterile deep water habitat at the base of the bulkhead. Filling of the shoreline is necessary to some extent for many of the shoreline erosion control or shoreline access construction projects discussed in this report. It is important to consider the habitat resulting from the construction when evaluating the preferred alternative. Vegetative erosion control measures will often require filling to provide a suitable substrate for the marsh plants, but the habitat created may be more biologically important than the shoreline they replace. Similarly, a riprap revetment will provide a much more diverse habitat than a bulkhead it might replace.

DREDGING

Like filling, dredging directly impacts the environment by physically removing bottom material and any organisms living there. The effects of dredging may be much more widespread than the immediate area of material removal, however. Dredging can greatly increase suspended sediment in the water, decreasing the light level reaching plant life on the bottom of the estuary, and impacting fish or shellfish. Dredging alters the nature of the bottom, often replacing productive shallow shoreline with deeper, less productive waters. Pockets of deeper water are often created by dredging operations, which can become isolated areas of water low in dissolved oxygen with soft, unproductive bottoms.

Disposal of the dredged material can often be as detrimental to the environment as dredging itself. At one time it was common to dispose of dredge spoil by discharging into nearby marshes. This destroyed valuable marsh habitat, leaving unproductive spoil areas in its place. Underwater dredge disposal can smother organisms on the bottom, concentrate suspended sediments in the water column, and replace valuable bottom habitat with less productive soft sediment substrate.

CIRCULATION MODIFICATION

Often dredging, filling, or shoreline construction will modify the existing circulation patterns in the nearshore area, adversely affecting the estuarine environment. Any alterations which change the nearshore topography from a gradually sloping bottom to deep water with a steep bank are likely to increase the current velocity of the nearshore area, making the area less useful as a nursery habitat for a variety of aquatic organisms. Removing vegetation or creating deeper water will also expose nearshore organisms to increased predation by removing protective cover or allowing larger fish to enter the area.

Other types of circulation modification which can be detrimental to the estuarine environment include changes due to channel dredging, which can introduce colder more saline water into an area, or which can allow freshwater to drain rapidly into the estuary instead of slowly filtering through marsh areas and shallow waters. Dead end channels and canals will often develop water quality problems due to lack of sufficient tidal circulation or flushing.

It will often be less of a disruption to the environment to build a pier out to deep water rather than dredge a channel or berth into the shoreline. If a berth is dredged into the shoreline it is preferable to keep it as shallow as possible and to streamline the ends to increase the circulation within the berth.

SCOUR AND SEDIMENTATION

Any modifications to the shoreline which increase bottom scour either during normal or storm conditions, or which increase sedimentation in productive bottom areas are harmful to the estuarine environment and should be avoided. Construction of vertical bulkhead walls seaward of the high water line will often induce scour during storms, leading to loss of material at the toe of the wall. Besides promoting failure of the wall, this can increase the suspended sediment load in the estuary, and remove nearshore bottom habitat. A sloping revetment wall of rough rubble is much less likely to cause scour under storm wave conditions.

Sedimentation includes the deposition of silt or sand around structures which interrupt the normal flow of material along the shoreline or nearshore area. This can include shoreline erosion control structures such as groins, which are designed to entrap sand moving along the shoreline, or shoreline access structures such as boat ramps, which can cause sedimentation problems if improperly placed or designed.

RUNOFF

Runoff of contaminated rainwater can affect the water quality of the estuary. Contaminants include fertilizers from yards or agriculture, sediment from construction or farm fields, oil and grease from parking lots and roadways, sewage treatment effluent from municipal plants or individual septic tanks, and industrial waste.

Proper design of shoreline erosion control and access structures can minimize runoff impacts by providing for elimination or filtration of the runoff before it reaches the estuary. Parking lot and roadway drainage can be routed through grassed swales or into stormwater detention ponds. A buffer of vegetation can be left between lawns and the water edge. Construction areas must be contained with proper silt fencing and other drainage controls. A shoreline protection design which incorporates vegetation can provide a very effective filter for contaminated runoff.

SHADING OF VEGETATION

Nearshore submerged vegetation requires adequate sunlight to survive. Shoreline access structures such as piers and boathouses can shade the bottom a significant portion of the day even when they are pile supported, reducing the productivity of the bottom vegetation. This effect can be minimized by keeping the structure an adequate distance from the bottom, keeping the structure as narrow as possible, and leaving spaces between decking boards.

Trees planted along the shoreline can adversely affect marsh grass by shading them. Marsh grass typically requires about four hours of direct sunlight per day to thrive, and shading can weaken it to the point where it can no longer provide erosion control for the shoreline. Shoreline erosion control projects incorporating vegetation require careful consideration of the placement of shade trees.

HUMAN USE

Shoreline access structures can increase human use of a shoreline, with the potential for greater litter and foot traffic. Shoreline access planning should include controls to safeguard vulnerable vegetated areas. Boat ramps, piers, moorings and boathouses will increase the boat traffic in the vicinity of the structures. Care should be taken in siting such structures to avoid areas of submerged aquatic vegetation, which can be easily damaged by boat propellers. Boat wakes can also increase erosion on vulnerable banks, destroying shoreline vegetation and increasing sediment loss into the estuary.

3.0 SHORELINE DEVELOPMENT DESIGN CONSIDERATIONS

In designing a structure, numerous decisions on structure location, height and shape must be made. The factors most important to structure design include water levels, wave heights, and environmental impacts. Other considerations include toe protection, soil properties, filtering, and flank protection.

WATER LEVELS

The maximum water level during storm conditions determines required elevations of structures to prevent overtopping and structural damage. In tidal waters, the water level is a combination of the tide and a storm surge. Spring tide levels can be determined from tide tables. Storm surge levels can be determined from local experience or from the local Flood Insurance Rate Map (FIRM) published by the Federal Emergency Management Agency (FEMA). The FEMA information for a particular area can be requested by mail from FEMA, Flood Map Distribution Center, 6930 San Tomas Rd., Baltimore, MD, 21227. Typical storm tides range from 4 to 7 feet in coastal waters. In the Gulf coast in extreme hurricanes the storm tide can reach up to 20 feet.

WAVE HEIGHTS

Wave heights are governed by wind speed, fetch (straight line open water distance to which a site is exposed), and water depth. Coastal engineering design manuals such as the U.S. Army Corps of Engineers "Shore Protection Manual" (1984) provide charts for determining wave heights. Wave heights can also be limited by the depth of water at the site. The maximum breaking wave height is approximately equal to the depth of water. If the bottom material in front of a structure is easily eroded, such as sand or soft mud, the water depth at the toe of the structure may increase over time. In this case either toe scour protection should be provided, or allowance should be made for increased water depth due to scour.

Wave *runup* is the vertical height above the stillwater elevation that the rush of water reaches on a structumines or beach after the breaking of a wave. Wave runup determines the height to which a shoreline erosion control structure should be constructed to avoid overtopping and damage to the back of the structure. Runup will typically range from a vertical height equal to the incident wave height for a stone revetment to twice the incident wave height for a vertical faced bulkhead.

It is often not cost effective to eliminate all overtopping by building an extremely tall structure. In many cases it would be more economical to allow some overtopping during large storms. In this case, the structure design should incorporate measures to minimize erosion behind the structure due to wave overtopping. This can include a rock apron or paving behind a bulkhead or revetment, or erosion-resistant vegetation such as turf grass planted behind the structure. The extreme elevation to which tides, surges and wave runup will reach is depicted in Figure 2.

SOILS CONDITIONS

Soil properties are important for determining the long term stability of coastal structures. Settlement, pile embedment, toe stability, and scour are determined by the surface soil properties. For small private projects, the knowledge of local contractors is often the best source of information on requirements for pile embedment, settlement, and scour. For larger projects, a soils exploration program will be justified. General suitability of various general soil types for coastal structures is as follows:

- Gravel: Difficult driving for wooden or other lightweight sheet piling. Excellent for stone structures.
- Sand, Silty Sands: Good for sheet piling, but toe protection will be required. Suitable for stone structures, but stone structures will also generally require toe protection. Commonly found along beaches and rivers.

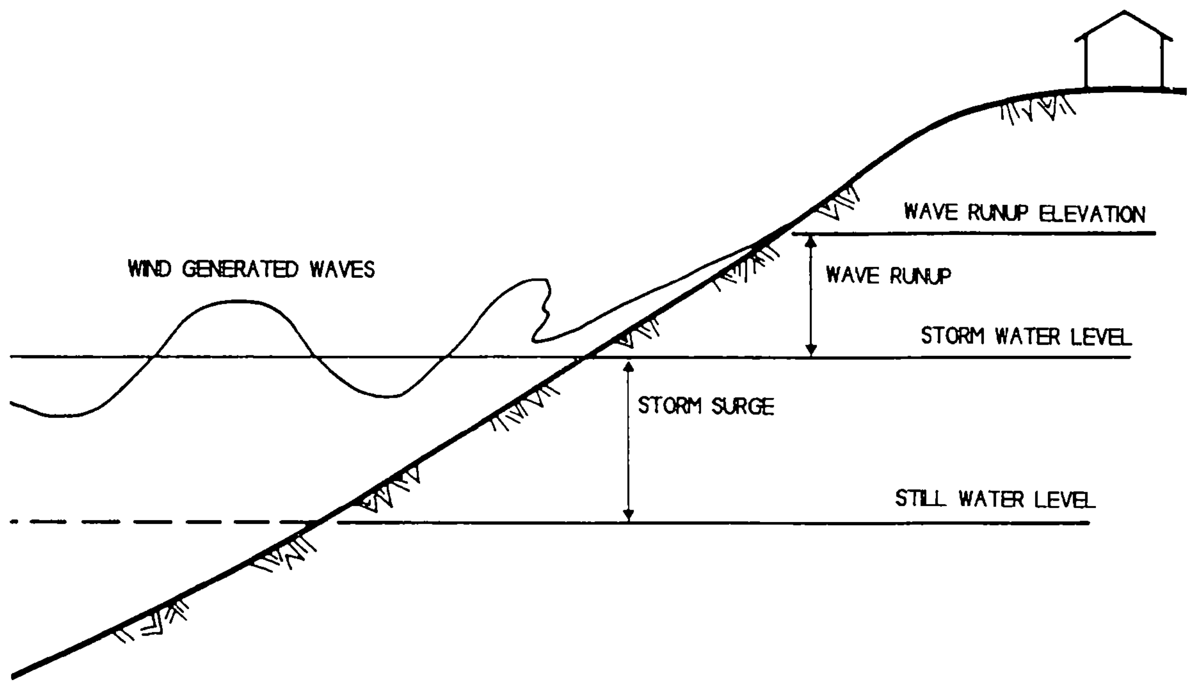

Figure 2. Elevation of Tides, Surges and Wave Runup on a Beach. (Univ. Wisconsin Sea Grant, 1987)

- Fine Grained Soils: Good for piles if firm. If soft, long embedment lengths may be required. Good for stone structures if firm. Excessive settlement may occur if soft.
- Organic Soils, Peats: Generally not acceptable unless piles bear on an underlying stratum. May result in large settlement of stone structures unless the layer is thin. These soils usually occur in low lying areas such as marshes.

SHORELINE CHARACTERISTICS

There are a wide variety of shoreline types. Each type of shoreline calls for different shore erosion control solutions.

Banks and bluffs are steep shoreforms consisting of soft erodible material such as clay, sand, or gravel. Bluffs are typically higher than banks, but no clear distinction is generally made. Bank erosion is typically due to a combination of seepage of groundwater within the bluff and erosion by wave action at the base. The most appropriate erosion protection may consist of a combination of a drainage system or slope flattening, plus wave erosion protection such as a revetment at the toe.

Wetlands are marshy areas that are saturated with water for much of the time and support vegetation adapted to saturated conditions. Previously often drained or filled to create new upland areas, marshes are now protected by federal and state regulations. Protection of marshes will often consist of a non-structural solution incorporating the planting of erosion resistant marsh grasses.

Beaches are the most common shoreform in the United States. Beaches are typically very dynamic, with the sediment moving onshore, offshore, and along shore in response to wind and wave conditions. Interrupting the movement of sediment along the shoreline by constructing jetties or groins can cause detrimental impacts to beaches adjacent to the construction.

SEDIMENTATION CONTROL

Care must be taken during construction to minimize sediment runoff into the estuary. Measures which can easily be incorporated into shoreline construction include sedimentation fences surrounding excavation and material storage areas. Some areas may have restrictions on construction during certain seasons to protect habitat or marine organisms during particularly vulnerable stages.

MATERIALS

Structures constructed along the shoreline of estuaries are exposed to severe conditions, including emersion in seawater, exposure to marine organisms, and public use. Materials used in their construction must be durable to obtain a reasonable useful life. Some of the most common materials include the following:

<u>Rock</u> is the most frequently used material for shoreline erosion control. Rock is generally durable and cost effective, when supplies exist within a reasonable distance from the project. Dense, sound rock will give the best long term performance.

<u>Wood</u> is used in many shoreline access structures, as well as bulkheads. Wood used in the marine environment should be chemically treated to resist rot and boring organisms. Creosote-treated timbers should generally be avoided due to the potential impact on the environment.

<u>Concrete</u> can provide a very durable construction material for shoreline access or erosion control. Because concrete is not as dense as quarrystone it is not as stable in waves. Concrete is available as pour-in-place, precast, and concrete rubble, depending on the application. Additives, such as air entrainment, can increase the durability of concrete in seawater. Care should be taken when using concrete rubble to ensure that the material is free of contamination such as petroleum products.

<u>Metal</u> is used in a variety of shoreline structures, including bulkheads and shoreline access structures. Steel with various properties and coatings is available to help withstand corrosion in seawater. Aluminum is available for small bulkhead walls.

<u>Elastomeric materials</u> such as plastic and rubber are used for floating docks, floating breakwaters, fishing reefs, and light-weight bulkheads. Care must be taken to ensure the plastic is properly formulated to withstand sunlight to provide a reasonable length of service.

REQUIRED LIFESPAN

Return period refers to the frequency of storms of a certain severity and is used as a design criterion. For instance, a structure can be designed to survive a storm which occurs on the average of once in 10 years, i.e. a return period of 10 years, more cheaply than it can be designed to withstand a storm which occurs on the average of once in 25 years. However, the risk that the structure will be damaged during its lifetime will be greater for the 10-year design than the 25- year design. It is recommended that permanent residential protection structures be designed for a minimum return period of 10 years, and preferably 25 years. Structures designed for 10-year return periods can be expected to require regular significant maintenance costs. Structures designed for 25-year return periods will require less regular maintenance, but may occasionally be damaged by large storms. Major projects should be designed for a 50- to 100-year return period.

GENERAL DESIGN METHODOLOGY

There are a number of general procedures recommended for the planning and design stages of shoreline construction projects. These procedures will vary somewhat depending on the size, scope, and type of project, but they provide a general guide for planning.

- Obtain general water depths governing navigation in the vicinity of the site from navigation charts. For erosion control structures, obtain cross-sections of the bank to be protected.
- For offshore access structures, measure water depths offshore beyond the expected limits of the structure.
- Estimate design water levels (tide plus storm surge) and potential wave heights to determine the design wave height for the site.
- For erosion control structures, estimate the wave runup on the structure.
- Obtain information on soils in the area of construction.
- Check with local agencies and the U.S. Army Corps of Engineers for environmental limitations on construction and for information on the permitting process.
- Lay out the structure using the cross-section survey.
- Consider the long term stability of the bottom in front of the structure, the shoreline adjacent to the structure, and the land behind the structure. Consider toe protection, flank protection (see Figure 3), and filter layer (see Figure 4).

There are a variety of available publications regarding shoreline erosion control which can provide additional detail on design methods. Examples include "Low Cost Shore Protection -A Guide For Engineers and Contractors" (U.S. Army Corps of Engineers, 1981) and "Shore Protection Manual" (U.S. Army Corps of Engineers, 1984). It is recommended that shoreline erosion problems be addressed with the assistance of a coastal engineer.

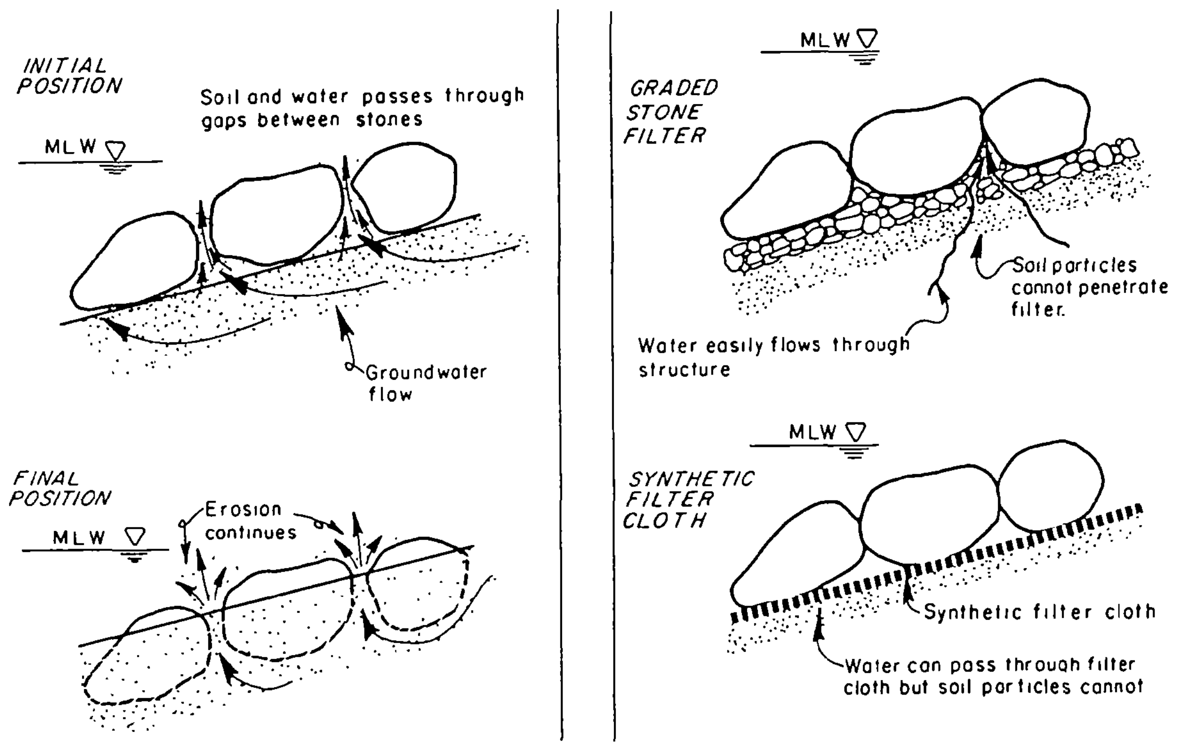

Figure 3. Filtering for Stone Structures (U.S. Army Corps of Engineers, 1981).

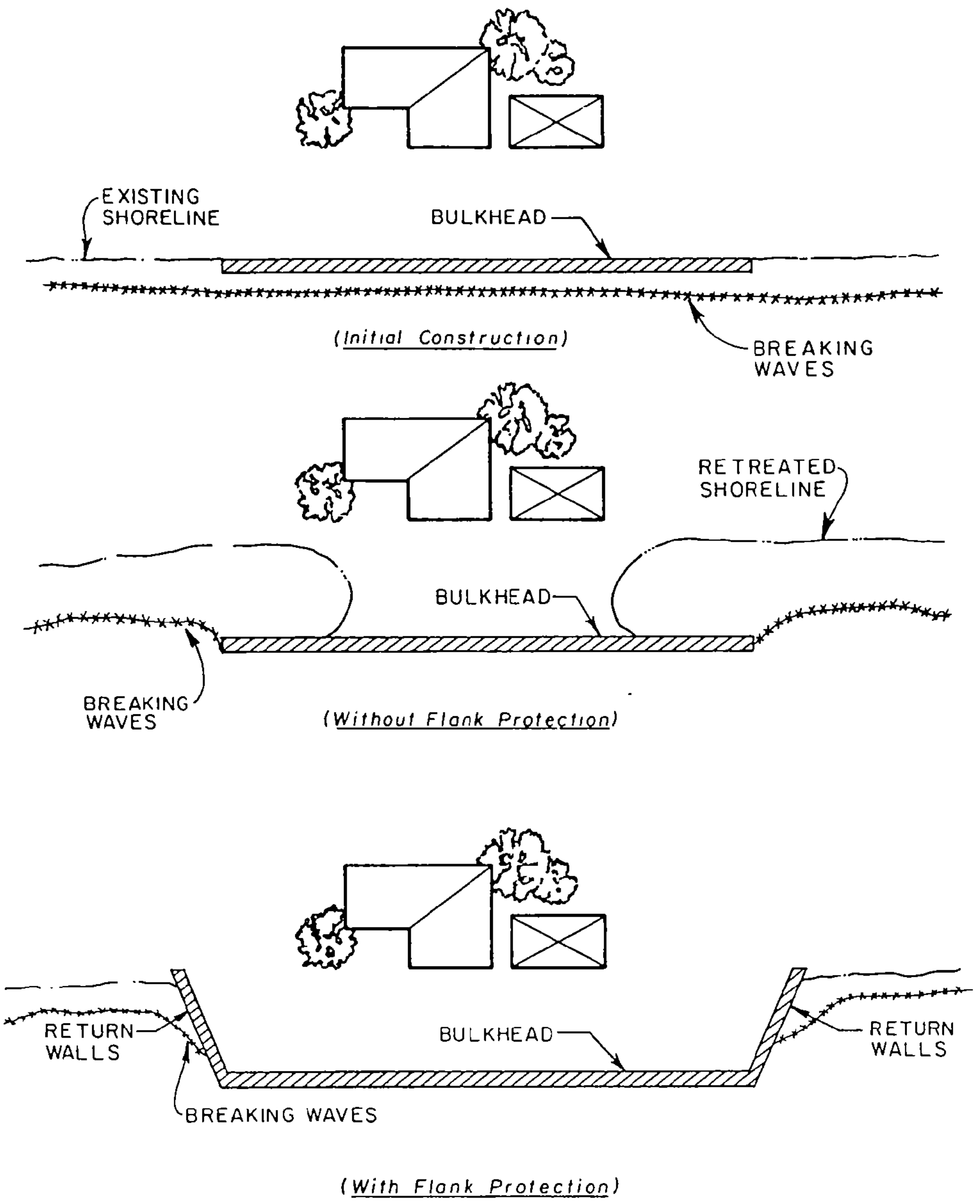

Figure 4. Example of Flank Protection (U.S. Army Corps of Engineers, 1981).

4.0 SHORELINE DEVELOPMENT ALTERNATIVES

SHORELINE EROSION CONTROL

Vegetation

a. Site Characteristics. Vegetation is most effective as a shoreline erosion control measure in relatively protected areas where wave heights are limited. For vegetation without auxiliary structures, such as those discussed in the next section, this generally means the maximum fetch (straight line length of open water) should be less than about one mile. The site should also be characterized by gentle slopes so a sufficiently wide band of shoreline between mean low water and highwater exists to support enough vegetation to effectively buffer the shoreline. Generally 15 to 20 feet of vegetation is required to provide adequate protection. A moderate tidal range on the order of several feet and gently sloping banks are more conducive to vegetation erosion control than are minimal tides and steep banks.

b. Environmental Consequences. Vegetated shorelines for erosion control are environmentally advantageous unless a healthy established ecosystem must be destroyed to establish the erosion control. Generally the sites considered for vegetation erosion control consist of eroding soil banks or marsh edges. In the latter case, the edge of the marsh is protected by establishing a gentle slope protected by new marsh vegetation in front, leaving the existing marsh undisturbed. With guidance from a professional coastal engineer, new marsh plantings can provide the same benefits to the estuary as does a natural marsh, including shelter, food and nutrients for a wide variety of organisms.

c. Human Shoreline Use. Vegetated shoreline control will generally limit the amount of use a protected shoreline can receive. The marsh grasses generally used are vulnerable to damage by regular foot traffic, and a well established stand of marsh grass is difficult to walk through. If access to the shoreline is desired in an area being considered for vegetated erosion control, special provisions should be made. This could include elevated wooden walkways, pocket sand beaches protected by groins, or gravel walkways.

d. Design Considerations and Limitations. Design of vegetation erosion control projects will include the following steps:

- Evaluate Site: The best indicator of a site suitable for vegetation erosion control is the presence of marsh vegetation within a short distance, or other erosion control projects in the vicinity.

- Determine Water Levels: The zone which should be planted with a particular species can be determined by observations of nearby natural marshes. The appropriate elevations for various common species is shown in Table 1.

- Sediment Supply and Stability: A moderate amount of sediment deposition on marsh grasses can have a beneficial effect by stabilizing exposed grass roots and filling eroded areas. Where there is excessive deposition, grasses can become irreparably damaged due to burial. A beach or fill which erodes rapidly after the marsh grass has been planted will result in plants washing out. Fills should be allowed to come to equilibrium before planting.

Additional information on vegetated erosion control can be obtained from "Planting Marsh Grasses for Erosion Control," by the University of North Carolina Sea Grant Program. Local County Extension or Sea Grant agents may have information on particular areas. The application of marsh grass for erosion control can be extended through the use of small structures, as discussed in the next section.

e. Cost. Vegetation will typically be the most economic method of shoreline erosion control for those areas which are suited to the method. Costs might typically include marsh plants for a 20-foot wide planting area, grading the bank, and filling the shoreline with sand to provide a uniform mild slope. Costs currently range from $20 to $50 per foot of shoreline (1992 cost estimate). Information about local suppliers of plants can be obtained from the U.S. Army Corps of Engineers, state, county or local

Table 1. Planting Specifications for Erosion Control (U.S. Army Corps of Engineers, 1981).

Type	Planting Time	Plant Form	Spacing	Location
Smooth Cordgrass	March-May	Sprigs 15 week seedlings 6-month seedlings or plugs	3' apart 1.5' apart 1.5' apart	MLW to MHW
Saltmeadow Cordgrass	March-May	Sprigs 15-week seedlings	3' apart	MHW to high tide
Gulf Cordgrass	March-May	Sprigs 15-week seedlings 6-month seedlings	1.5'-3' apart 1.5' apart 1.5' apart	MHW and above
Salt Grass	Spring	Seedlings	1.5'-3'	MHW and above
Black Needle Grass	Spring	Seedlings	1.5% of Cordgrass plantings	Above MHW
Common Reed	Spring	Sprigs	1.5'-3'	Above MHW
Mangroves	Feb.-March	Seedlings established Plants	1.5' apart 6'-10' apart	MTL and above

government offices that issue permits for coastal shore protection projects.

f. Expected Lifetime. The lifetime of a vegetated shoreline erosion project will depend greatly on the suitability of the site, storm occurrences, and care and maintenance. For a site with a limited fetch with a well established marsh the main cause of failure of the vegetation will be neglect. Debris allowed to accumulate on the marsh will kill vegetation, and should be removed on a regular basis. Trees should be properly located to prevent shading of the marsh grass. The best treatment to ensure a long life is regular fertilization with a slow-release fertilizer. This will keep the marsh grass healthy and dense, providing the best protection against erosion.

g. Cumulative Effects. The cumulative effects of appropriately vegetated shorelines in any estuary will be positive. Planting marsh grasses for erosion control will help reverse the long history of destruction of marshes in estuaries in the United States.

h. Regional Considerations. Atlantic coast marshes will typically consist of smooth cordgrass (*Spartina alternaflora*) below mean high water (MHW) and saltmeadow cordgrass (*Spartina patens*) above MHW to the estimated highest tide. Other common species will include black needle rush (*Juncus roemerianus*), common reed (*Phragmites communis*), and mangroves. Gulf coast marshes will include gulf cordgrass (*Spartina spartinae*) and saltgrass (*Distichlis spicata*). Both of these later species are planted above MHW. Other regional considerations involve tidal ranges. As noted previously, areas with minor tidal variations are less likely to have sufficient intertidal area to provide sufficient width for vegetation to provide reliable erosion control. The exception to this will be areas which have extremely flat shoreline, or which can be filled or graded to provide very flat shorelines. Refer to Table 1.

Sills

There are a large number of shorelines in estuaries which could benefit from vegetated erosion control, but which are exposed to waves that are too large for the vegetation to become established and stable. One alternative which is often practical and economical is to extend the range of marsh plantings with a protective structure known as a sill. The sill is similar to a breakwater, except it is much smaller and is designed to provide protection to the fill and marsh plantings behind it. Typically such a structure will be constructed from stone, be located between mean low water (MLW) and one foot below MLW, and have a crest elevation approximately a foot above mean high water (MHW). An example of a stone sill schematic is shown in Figure 5 and a stabilized shoreline using this technique is presented in Figure 6.

a. Site Characteristics. Sites suitable for vegetated shoreline erosion control in conjunction with a sill typically have fetches of one to three miles, although such projects have been successfully built in areas with fetches much greater than this. Other site characteristics are similar to vegetated shoreline erosion control sites.

b. Environmental Consequences. The environmental consequences of sills, when combined with marsh planting for erosion control, are very positive. A relatively minor amount of habitat is lost below the sill structure as compared to other erosion control alternatives because the structure is relatively small in size. The small stones from which the sill is constructed will provide habitat to a range of organisms. The marsh plantings will provide the environmental benefits discussed for the vegetated shoreline erosion control.

c. Human Shoreline Use. The use of sills in combination with marsh plants for erosion control places the same constraints on human use as does vegetated erosion control alone. In general, regular or intensive foot traffic must be prevented on the marsh plants. Alternative access should be provided if shoreline use is desired.

d. Materials. Sills are normally constructed of graded quarrystone. The size of the stones and the size and cross-section of the sill are determined based on wave conditions.

e. Design Methodology and Limitations. The design process will include the basic considerations discussed in Section III and the procedures for vegetative erosion control discussed in the preceding section (Section 4). Other considerations include the following:

- The sill is generally designed for shallow water with the stability of the armor governed by the wave height with the water level at the crest of the structure. At higher water levels the structure is submerged, compensating for the greater wave heights possible with the greater depths.

- The crest height is generally set so that the toe of the fill on the back side of the sill is 1.0 to 2.0 feet lower than the crest.

- In some cases, breaks in the sill should be provided to allow water into and out of the marsh behind the sill. The area behind these breaks should be carefully designed to avoid unacceptable erosion in these areas, either with a stable sand beach or additional low stone riprap.

In some cases, a sill-like structure can be useful in stabilizing an eroding edge of an existing marsh. Typically clumps of marsh vegetation will be eroded by wave action, creating a *scarp*, or vertical face, at the new marsh edge that drops a foot or more into the water. This scarp will continue to march landward as the marsh edge is eroded by wave action even though the marsh itself is stable in waves passing over the top of the plants. In this case the edge can be stabilized by a sill built as close to the scarp as possible. The area between the marsh and sill is filled with sand, and marsh grass planted. With the edge stabilized, erosion generally is stopped and the marsh is stable in all wave conditions.

f. Cost. Next to vegetation alone, sills combined with vegetation are generally the least expensive shoreline erosion control methods. Costs include the sills themselves, plus the costs of grading, filling and marsh planting. Currently, typical current costs range from $75 to $150 per foot of shoreline, although costs could be greater for deeper water and more fill (1992 cost estimates).

g. Expected Lifespan. The same comments on expected lifetime listed for vegetated erosion control also apply to the marsh grass portion of the sill shore protection system. In

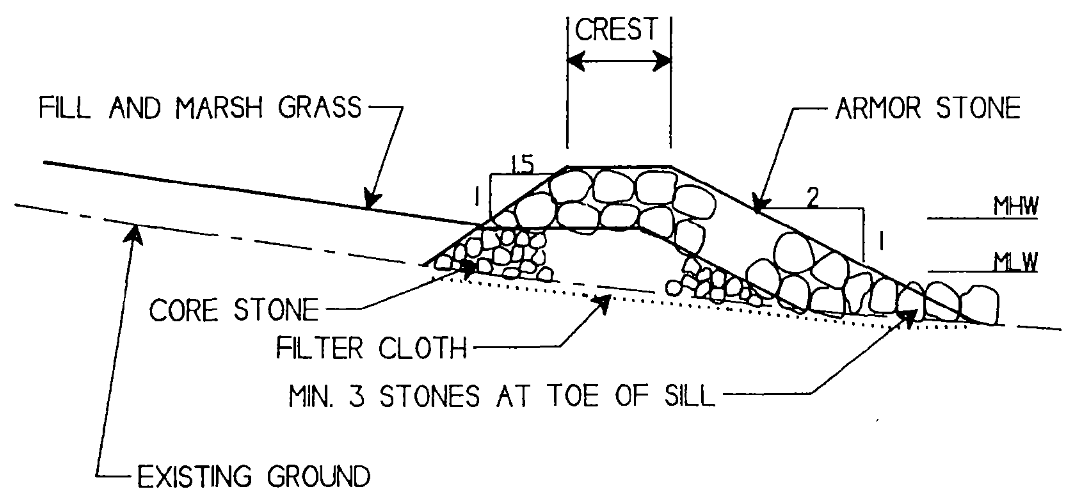

Figure 5. Schematic of Stone Sill with Marsh Creation.

addition, the sill should be periodically inspected for damage. The small size of the stones often makes it easy for limited damage to be repaired by hand. Special attention should be paid to the toe of the structure and the ends of the structures to ensure that they are not being undermined by erosion. If this is occurring additional stones may be placed in the eroding areas. With proper maintenance, a stone sill erosion control system should have an indefinite life.

h. Cumulative Effects. The cumulative effects of sills in combination with vegetation for shoreline erosion control should consist of the same positive benefits to an estuary as vegetation alone, including additional marsh habitat, elimination of erosion, and filtering of runoff.

i. Regional Considerations. The regional considerations discussed previously for vegetated erosion control also apply to the planted portion of sill projects. In addition, the availability of economical supplies of stone will affect the designs in some regions. Other materials such as concrete may be more economical in areas where rock supplies do not exist.

Beach Fill

Beach fill consists of sand applied to an eroding beach area, or to an area where a recreational beach is desired. In an estuary, a beach fill will typically be combined with some type of fill-retaining structure such as groins, breakwaters, or sills. Figure 7 shows a typical cross-section for a beach fill project.

a. Site Characteristics. A site suitable for a beach fill will typically consist of an already existing sand beach which has been eroding, no longer offering adequate protection to the shoreline. In some cases the erosion of the beach may be due to the interruption of the natural movement of sand due to other shoreline erosion control structures. Beach fills are often used to fill between groins, and behind breakwaters and sills to restore the natural shoreline protection a beach provides. In an estuary where the natural shorelines are typically irregular, sand beaches generally must be confined by some type of natural feature such as rock outcroppings (headlands), or manmade features such as groins. Small sand beaches often exist at the base of banks and bluffs, which provide a steady source of sand as they erode back. If the source of sand is cut off by an erosion protection structure such as a bulkhead or revetment the beach may quickly disappear.

Figure 6. Stabilized Shoreline Using Sill and Marsh Grass.

b. Environmental Consequences. If beach fills are used to replenish already existing beaches which are eroding, the environmental impact to the area will generally be minor. If sand fill is placed over a marsh bottom or some other type of productive bottom, important habitat may be lost. Generally, beach fills should only be considered for areas already consisting of sandy beach.

c. Human Shoreline Use. Generally, sandy beaches are the most heavily used shorelines for recreation. A beach fill can restore or create a highly desirable recreational area, increasing human traffic and impacts. If a beach with public access is created, there should be careful consideration of the possible increased traffic, parking, litter, and human waste. Environmental impacts can be minimized by proper drainage of parking areas, providing refuse containers and rest rooms, and regular cleanup.

d. Materials. Beach fills are constructed of medium- to coarse-grained clean sand. The selection of sand type and gradation is based upon the type of beach use, the wave and tidal conditions, sand availability and cost and other factors.

e. Design Considerations and Limitations. Design techniques for beach fills are described in U.S. Army Corps of Engineers "Shore Protection Manual" (1984). Some of the items important to proper beach fill design include the following:

(1) The beach fill material should have characteristics similar to the natural beach. The grain size and grain size distribution should be similar to, or slightly coarser than the existing material.

(2) The beach fill should be placed on a flat slope similar to the existing beach slope. Generally slopes should

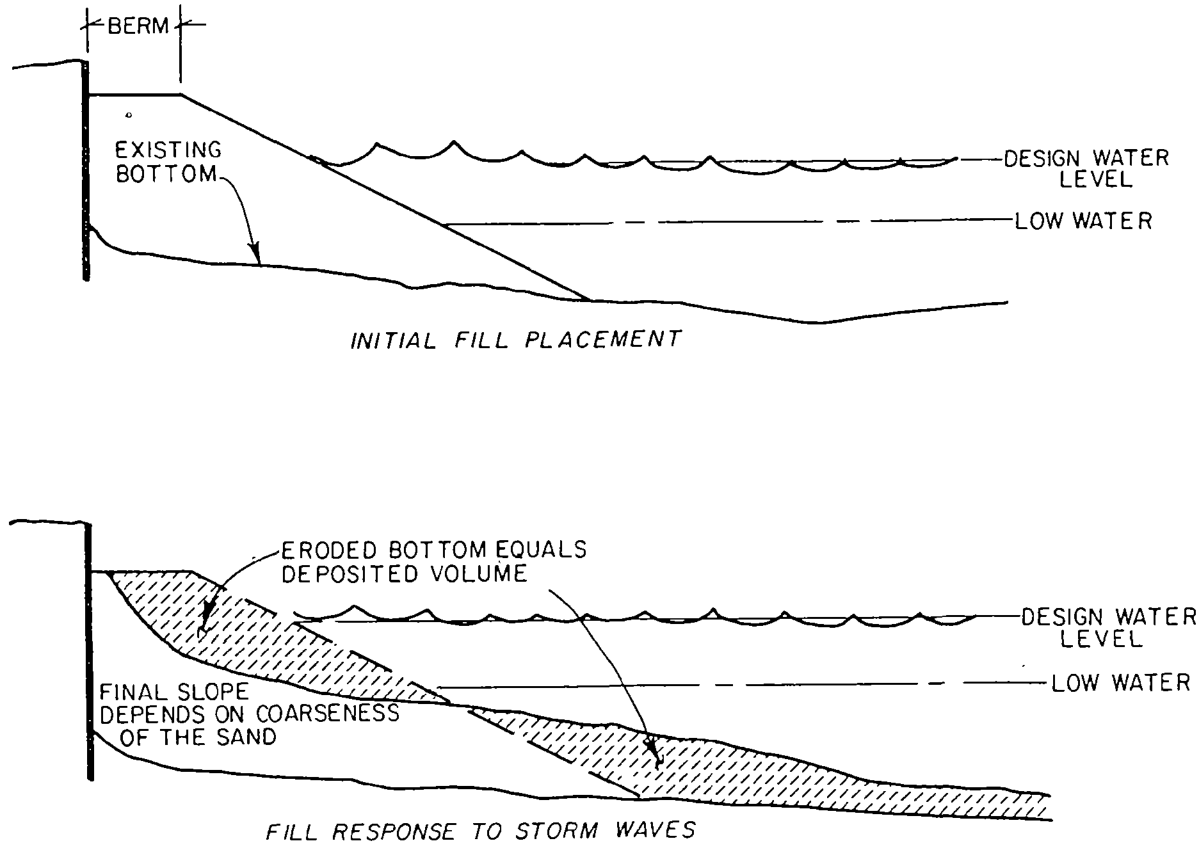

Figure 7. Cross-Section of Typical Beach Fill Project.

be in the range of 1:10 to 1:15, with finer material placed on flatter slopes.

(3) The material can be initially placed on steeper slopes to make construction easier, with final adjustment to natural slopes taking place by wave action. In this case sufficient material must be provided to create the desired beach width after final wave adjustment.

Limitations to beach fills include the following:

(1) Beach fills generally cannot provide complete protection to banks or bluffs under very high storm waves and water levels. Sand will generally move offshore under major wave attack, and then move back onshore under more typical summer wave conditions.

(2) A small local fill of beach sand will be rapidly lost to adjacent shorelines if it is not confined in some manner. Either the beach fill should consist of a long stretch of beach, or the fill should be confined by natural barriers such as stone outcroppings (headlands), or manmade structures such as groins or breakwaters.

f. Cost. The cost of beach fill will depend greatly on the availability of local suitable sand sources. The cost of sand with good access to nearby sand pits will be moderate, in the same range as a sill and vegetation shoreline erosion project, typically from $15 to $25 per ton. In some cases sand may be available at low cost from nearby dredging projects. If dredged material is considered for a beach fill, it must be demonstrated that the material is suitable for beach fill, and does not contain unsuitably fine material which will be washed away by normal wave action. The cost of periodic replacement of beach fill in areas undergoing steady erosion should be considered when planning beach fills.

g. Expected Lifetime. The life of a beach fill will vary greatly depending on the design, protection provided by natural or manmade features, and storm conditions. If a beach fill is placed in an area which has been undergoing natural erosion, it can be expected that the placed fill will also be eroded at a similar rate. Sufficient sand should be placed to provide at least several years protection at average erosion rates. If the sand fill is confined, it may last many years without requiring additional placement. Past experience with sand loss is the best guide to future sand loss.

h. Cumulative Effects. The cumulative effects of beach fills will generally be minor if they are placed only in areas of existing eroding beaches. The creation of recreational beaches should be limited to areas where the sand fill will not smother existing vegetation or valuable bottom habitat. Other cumulative effects associated with greater recreational use of the shoreline can be minimized if attention is paid to parking, litter, and other human use problems.

i. Regional Considerations. The major regional difference in the suitability of beach fills will be due to the existence of natural sand beaches. In estuaries with limited existing sand beaches, more care must be taken to ensure that existing valuable bottom habitat is not lost due to filling with sand.

Breakwaters

Breakwaters have been used with increasing frequency in recent years for shoreline erosion control in estuaries. They can often be used as an alternative to bulkheads or revetments, lessening the environmental impact. This type of structure is typically placed offshore with sections on the order of 100 feet long alternating with gaps of similar dimension. The breakwater segment length, distance offshore, and gap width are the major design features. Shoreline response to offshore breakwaters is shown in Figures 8 and 9.

a. Site Characteristics. Breakwaters are often used in areas with limited sand beaches fronting banks or bluffs. In these cases, either additional sand accumulates behind the structures by natural accretion, or sand is placed as part of the erosion control project. The combination of the reduction in wave height by the breakwater and the additional width and height of the beach provides the shoreline protection. Breakwaters are also used to protect the seaward edge of marshes from erosion by reducing incident wave energy.

b. Environmental Consequences. The impacts of breakwater construction on the environment include the loss of bottom habitat under the structure, construction-related disturbances such as temporary increased levels of suspended sediment, and alterations to the shoreline along the area protected. In many cases the loss of bottom habitat under the structure is compensated by the new habitat created in the stone breakwater. The area behind the breakwater will become more protected, perhaps leading to the accumulation of sand or finer sediments. The protected area will, in many cases, provide an enhanced environment for submerged aquatic vegetation. Marsh grasses will also often thrive along the protected shoreline if they are planted in suitable substrate.

c. Human Shoreline Use. Offshore breakwaters are often a good choice when access and continued use of sand beaches fronting banks and bluffs is desired. They do not interfere with access, or cover or destroy the beach as revetments or bulkheads may. The distance breakwaters are constructed from shore will control the pattern of sand deposition along the beach. Sediment will deposit in areas that are sheltered from wave energy. If the structures are placed very close to the shoreline sand may accrete and may eventually form a sand feature that extends from the shoreline to the structure, blocking the longshore movement of sand. Depending upon the project location, this blockage of longshore sand transport may not be desirable because neighboring shorelines may erode due to the blockage of normal sediment supplied from the breakwater-protected area.

d. Design Considerations and Limitations. Proper positioning of offshore breakwaters to obtain the proper relationship of length, gap width, and distance offshore is

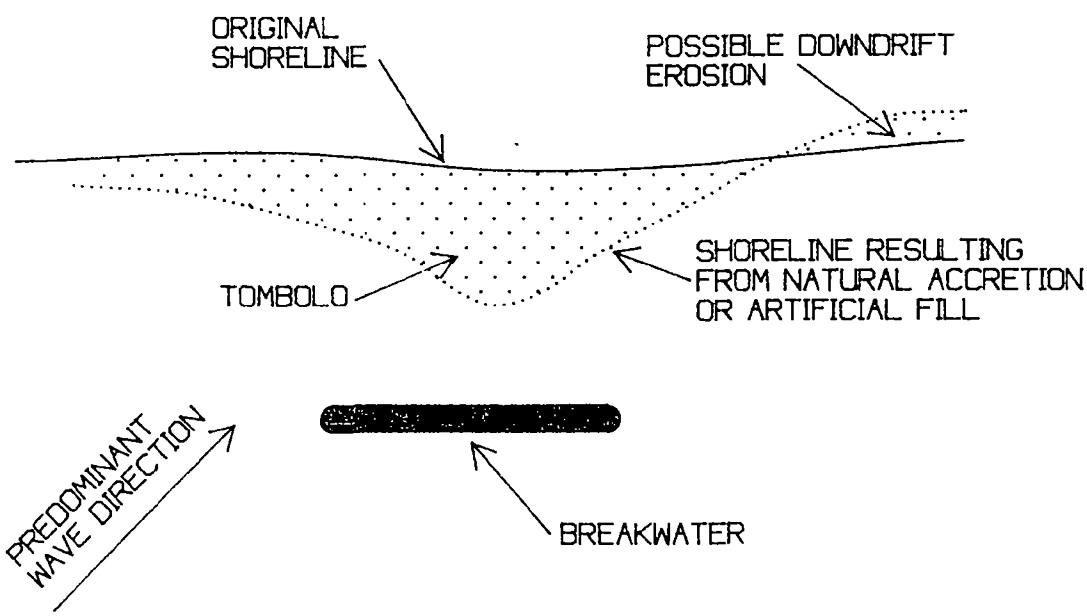

Figure 8. Schematic Plan View of Shoreline Response to Offshore Breakwater.

necessary for proper performance. Therefore it is recommended that professional assistance be obtained for design of this type of shore protection.

Breakwaters may not be as practical as revetments in some situations where complete protection against erosion is desired for high banks or bluffs. Typically the accumulated sand behind breakwaters provides excellent erosion protection to the top of the beach; but with extreme high water levels and storm waves, erosion can take place in the bank above the beach. Breakwaters may also be less economical or not practical in coastal areas where the water becomes deep within a short distance from the shoreline.

e. Cost. Breakwaters can vary considerably in cost, depending on water depths, tide range, and sources of good armor stone. Costs typically will be greater than for sills or vegetation and similar to revetments and bulkheads. Typical current costs range from $250 to $500 per foot (1992 cost estimate).

f. Expected Lifespan. Breakwaters will have a long lifespan if designed properly and maintained on a regular basis. Causes of premature failure of breakwaters include toe scour and foundation failures, stone deterioration due to poor stone quality, and stone displacement due to undersized stone or deficient construction.

g. Cumulative Effects. Extensive use of offshore breakwaters within an estuary will lead to changes to the character of the shoreline and to the bottom in the protected areas. None of these changes are obviously detrimental to the environment since equally productive habitats might be created. The most important aspect to consider is the character of the bottom and shoreline under consideration. Extremely productive or valuable habitat such as submerged aquatic vegetation, shellfish beds, or marsh areas should not be covered or altered by breakwater construction.

h. Regional Considerations. Offshore breakwaters will be most useful in regions with shallow nearshore waters and banks with a good supply of sand. Breakwaters are less useful in areas with deep water near the shoreline and high bluffs with little sand. Breakwaters will be more expensive in areas without a local supply of good armor stone.

Figure 9. Offshore Breakwater Project.

Revetments

Revetments are erosion-control structures generally constructed directly on an eroding bank or shoreline. Revetments consist of a rough sloping armored face, toe protection to prevent scour at the base of the protection, and a splash apron to prevent erosion of material behind the structure due to wave overtopping. A typical cross-section of a revetment is shown in Figures 10 and 11.

a. Site Characteristics. Revetments are generally suitable for protecting low banks from erosion when a recreational beach is not required. In some cases beaches may form or remain between a revetment and the water but the revetment structure will often cover narrow beaches, and scour from increased wave reflection may reduce the amount of sand deposited in front of the structure.

b. Environmental Consequences. Construction of revetments can cause alterations to the shoreline and loss of valuable nearshore habitat. This is especially true when the revetment extends below MLW. In this case the shoreline can be changed from a gently sloping vegetated shoreline with extensive shallows to a steep shoreline with limited shallow water. In other cases where the revetment is built on a steep eroding bank, little habitat will be lost, and a source of suspended sediments will be removed. In general, revetments should not be built where they cover or displace vegetated shorelines or nearshore bottom. Revetments can be built landward of MLW resulting in less impact and displacement of valuable habitat. Care should be taken in these cases that the material seaward of the toe is stable, since the revetment can cause increased bottom stresses by reflecting a portion of the storm wave energy seaward. Lawns are often planted to the edge of the revetment, increasing runoff of fertilizers and pesticides into the estuary. A buffer strip or drainage away from the shoreline should be incorporated into the revetment design to minimize this effect.

c. Human Shoreline Use. A revetment can improve the view and increase upland property by allowing the owner to

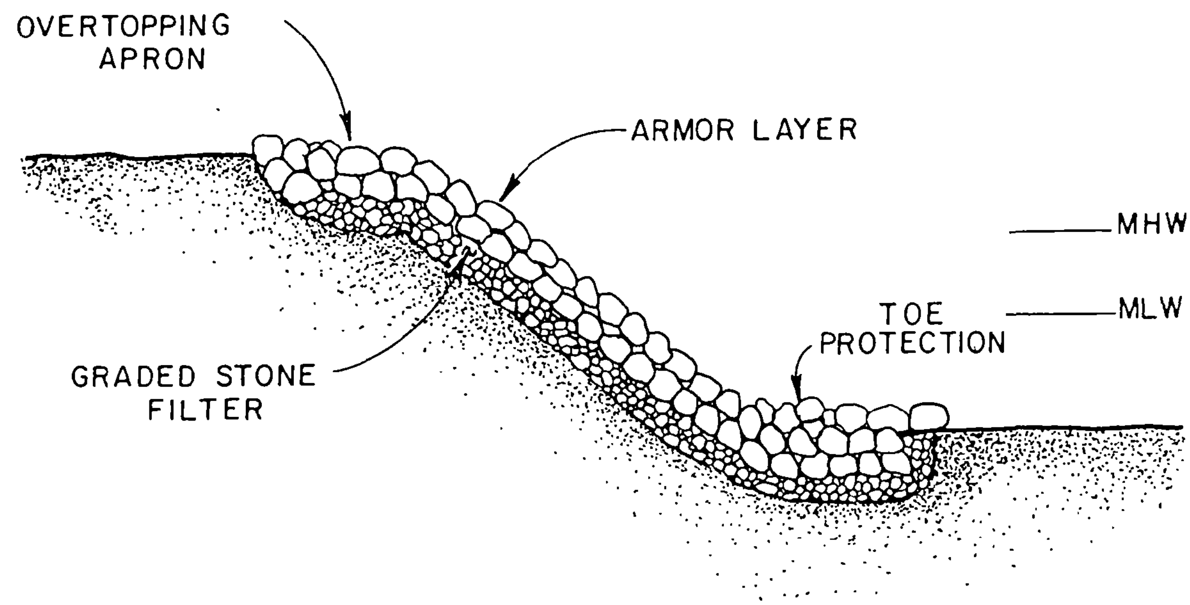

Figure 10. Typical Revetment Section.

plant a lawn almost to the waters edge. However, revetments often restrict access along the beach, especially at higher water levels. In some cases the revetment causes beaches to erode completely, preventing access along the shoreline at all water levels.

d. Design Considerations and Limitations. There are a number of good guides to the construction of revetments available, as listed in the appendix "Additional Information." Some of the main concerns with construction of revetments include

(1) Adequate toe protection should be provided to prevent damage due to removal of material at the base of the structure. This is especially important for revetments built on sand.

(2) A revetment should be tied to adjacent structures or properly stabilized at each end of the structure to prevent erosion on either side of the structure which could cause failure.

(3) Revetments can rarely be economically built high enough to eliminate all wave runup and overtopping. The area behind the structure should be designed to resist erosion due to the wave overtopping. This can be done with rock aprons and turf grasses.

e. Cost. Revetments generally cost approximately the same as offshore breakwaters, $250 to $500 per foot of shoreline, with costs varying widely depending on wave conditions, type of shoreline, and location.

f. Expected Lifetime. Maintenance and repair will be required to keep the structure in good condition, but if the structure is properly designed for the local wave conditions and the rock is of good quality, a revetment should last for an indefinite period. One limitation to the life of a of the revetment is the long-term stability of the seafloor at the toe structure. If the seafloor erodes away, the revetment will eventually fail unless additional toe stone is placed.

g. Cumulative Effects. A large number of revetments in an area will lead to changes in the composition of the shoreline, eliminating shoreline vegetation which provides

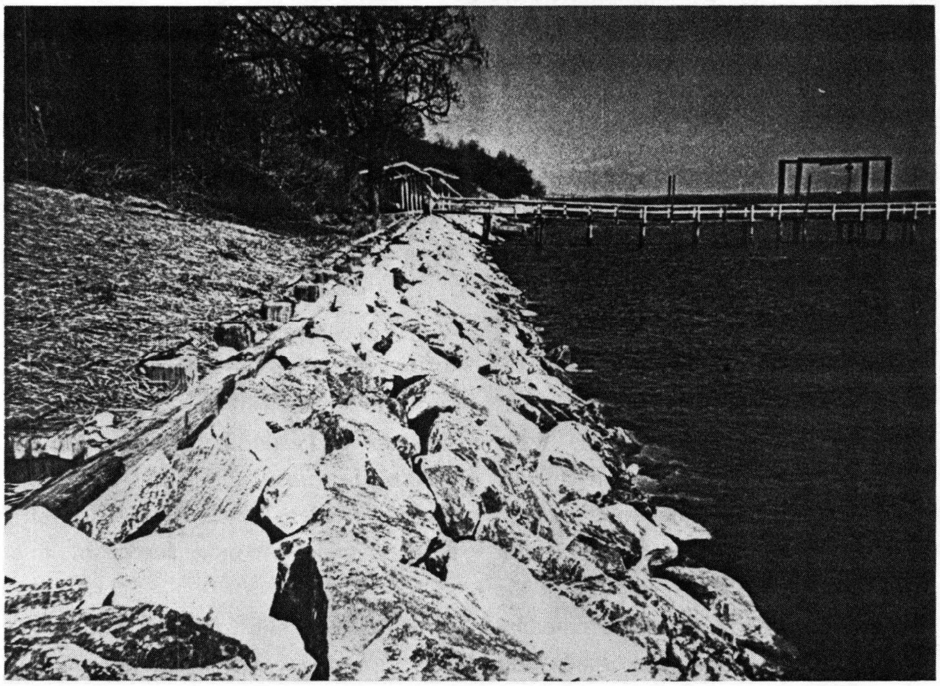

Figure 11. Functioning Revetment.

valuable filtering of runoff into an estuary. Revetments should be used for steep banks only where other shoreline erosion methods incorporating vegetation are not acceptable. Revetments will also increase scour below MLW at the toe of the structure during storm conditions, eliminating shallow water habitat and increasing suspended sediment loads.

h. Regional Considerations. Revetments are most applicable to those regions with extensive eroding steep banks, as opposed to shallow, vegetated shorelines. Revetments are most economical in areas with local stone supplies, although there are a large number of designs incorporating precast concrete units.

Groins

Groins are small structures built perpendicular to the shoreline to prevent the longshore movement of sand due to oblique wave attack. These structures are sometimes used to build beaches by trapping sand which would otherwise be carried along the shoreline, but this can cause erosion of other areas whose sand supply has been interrupted. Groins are better used in conjunction with sand fill, to confine the artificially-placed fill and maintain a healthy beach. Figure 12 depicts the use of groins along a shoreline.

a. Site Characteristics. Groins are best used along existing beaches where stabilization of the beach is desired. Filling between the structures with sand to prevent erosion downdrift of the groins is nearly always recommended. Groins will be most satisfactory on beaches which are oriented within 45 degrees of normal to the incoming waves. Areas with waves at larger angles would require extremely closely placed groins to create stable shorelines.

b. Environmental Consequences. The major impact of groins will be the loss of bottom habitat under the groin itself, and under the sand accumulated between the structures. Since groins are generally built only on sandy beaches, the environmental impacts will generally be minor.

c. Human Shoreline Use. Groins can be used to stabilize sandy beaches, which can result in increased human use of the shoreline. They can interrupt traffic along beaches if the structures are large.

d. Design Considerations and Limitations. The major design features of groins are their length, height, and spacing. These factors determine how effective the structures will be in limiting sand movement. Improperly design can accelerate loss of sand; therefore professional guidance or local experience should be used when designing these structures.

Another limitation of groins is that they do not prevent the movement of sand offshore during extreme wave conditions. Therefore sand may be lost in major storms, exposing the bank to erosion. In addition, care must be taken to ensure that groins do not cause increased erosion further down the shoreline due to the interruption of the natural movement of beach sand. This can be prevented by filling the area between the structures with sand after construction, so the natural movement of sand continues over the groins.

e. Cost. The cost of groins will vary greatly depending on the site and scale of the project. An area with small waves might consist of 20-foot groins with a spacing of 40 feet at a cost similar to a sill and vegetation, \$75 to \$150 per foot of shoreline. A more exposed area would require longer structures with greater spacing, costing as much as \$250 to \$500 per foot of shoreline (1992 cost estimates).

f. Expected Lifetime. Groins can last indefinitely if well designed and maintained. Erosion at the toe of the structure, erosion of the bank at the landward end of the structure, and material degradation can all lead to premature failure of groins. Erosion at the toe of a groin can be a special problem since groins are often built on sand beaches, which are more susceptible to erosion.

g. Cumulative Effects. If groins are confined to already existing sandy beaches, the cumulative effects within an

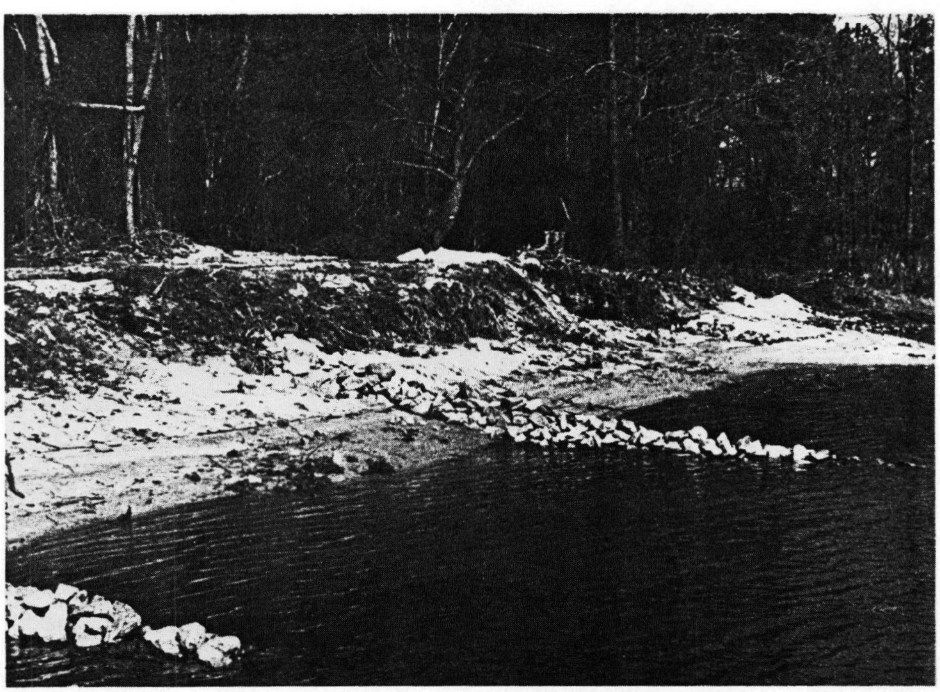

Figure 12. Rubble-Mound Groin.

estuary are expected to be small. Some alteration to the shoreline takes place, especially if scour around the seaward ends of groins removes bottom habitat and increases suspended sediments. Generally, however, the shoreline will retain its original characteristics and shoreline habitats.

h. Regional Considerations. Groins are best suited to regions with existing sandy beaches and moderate tide ranges and are less suited to marsh shorelines. The structures can be constructed of stone or many other materials, making them more attractive for sites without a local supply of stone. Wood, steel and concrete sheet piles are all commonly used for groins, although vertical-faced structures consisting of these materials will increase scour at the toe of the structure as compared to that occurring at the toe of a groin constructed of stone.

Bulkheads

Bulkheads are vertical walled structures which retain fill and protect the shoreline from erosion. Bulkheads are often favored by landowners because they can extend the useable dry land up to the waters edge, and in some cases provide boat mooring at the property's edge. As discussed in the introduction, bulkheads are associated with some of the worst impacts on estuaries. Figure 13 shows a typical cross-section for a bulkhead.

a. Site Characteristics. Bulkheads have been used on almost every type of estuarine shoreline. They are most commonly associated with low banks, with the top of the bulkhead above a typical high water elevation, and the land sloping down to the landward edge of the bulkhead. Bulkheads are also used to protect the toe of high banks and bluffs, and the edges of marshes.

b. Environmental Consequences. The major environmental harm to estuaries from shoreline development has been due to bulkheading and filling of marshlands to create land developments. This has removed extensive marsh habitat and shallow water habitat, replacing it with unproductive deep water at the toe of the bulkhead which is subject to increased scour during wave conditions due to reflections off the vertical face. Bulkheads are in general the least environmentally acceptable shoreline erosion control alternative because they provide no habitat or protected areas for marine life. The undesirable environmental effects of bulkheads can be minimized by building the bulkhead landward of the MHW line, with a fringe of vegetation or rubble in front.

c. Human Shoreline Use. Bulkheads provide good access to the water edge for the homeowner, but generally restrict movement along the shoreline by creating deep water along the bulkhead.

d. Design Considerations and Limitations. One major environmental and maintenance problem with bulkheads is scour at the toe. It is generally recommended that riprap stone be placed at the toe of bulkheads to limit scour. The riprap also provides additional habitat for marine organisms. Bulkheads also frequently lead to direct runoff from lawns and driveways. Buffer strips of vegetation seaward of the bulkhead can help filter this runoff, or the runoff can be channeled into swales which lead to marsh areas to filter the water.

e. Cost. Bulkheads are typically relatively expensive, depending on the size and complexity. Typical bulkheads will cost approximately the same as breakwaters and groins, with current costs ranging from $250 to $500 per foot of shoreline (1992 cost estimate).

f. Expected Lifespan. The life of a wooden bulkhead typically ranges from 10 to 30 years. Concrete bulkheads can be expected to have longer lives, while the lifespan of steel or aluminum bulkheads will depend greatly on the environment and protection applied to the metal.

g. Cumulative Effects. As discussed previously, cumulative effects of bulkhead construction in estuaries has led to significant modification of certain shorelines, associated with the loss of considerable fishery production. The proper design of bulkheads, primarily locating them above MHW with a beach, riprap or vegetation seaward of the bulkhead will help minimize these effects; but bulkheads will, in general, have the largest effect on the environment.

h. Regional Considerations. Certain estuaries have had such extensive development and bulkhead construction that additional bulkheading should be avoided. Other areas with only limited existing bulkheads might allow bulkheads under certain conditions if they are properly designed, and are built above MLW.

Other Options

Other options which are often used in conjunction with one or more of the above erosion control techniques include infiltration and drainage controls and slope flattening. These actions stabilize bluffs against erosion due to flowing water and may be required even when all erosion due to waves at the base of the bluff is prevented by a revetment or some other means. An example of a well-designed shore protection system might incorporate drainage control, slope flattening, vegetation, and shoreline protection. Such a project is shown in Figure 14.

Other options which must always be considered when evaluating a particular situation include the following:

No Action consists of allowing nature to take its natural course, without attempts to slow erosion. This option will often have the least objectionable environmental consequences and will obviously have the least cost. It may not be acceptable because of continuing losses of property.

Relocation consists of removing vulnerable structures from behind an eroding shoreline, either to another site or far enough from the shoreline to give an acceptable service life before again being threatened by erosion. This option will also generally have minimal environmental impacts on the marine environment.

WATER ACCESS CONSTRUCTION

Launch Ramps

A launch ramp is a sloping hard-surfaced structure used for launching boats from trailers, and also in some instances, providing water access to amphibious aircraft. Boat ramps are built as public facilities, where they can incorporate many lanes as well as piers, and as private facilities, where they will typically be much simpler.

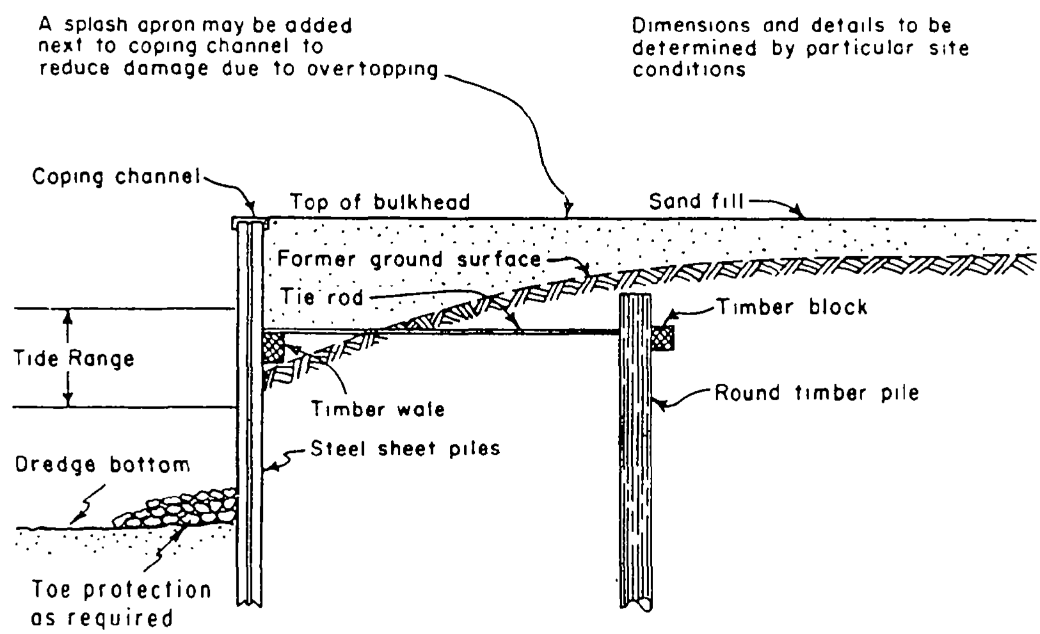

Figure 13. Typical Cross-Section for Bulkhead.

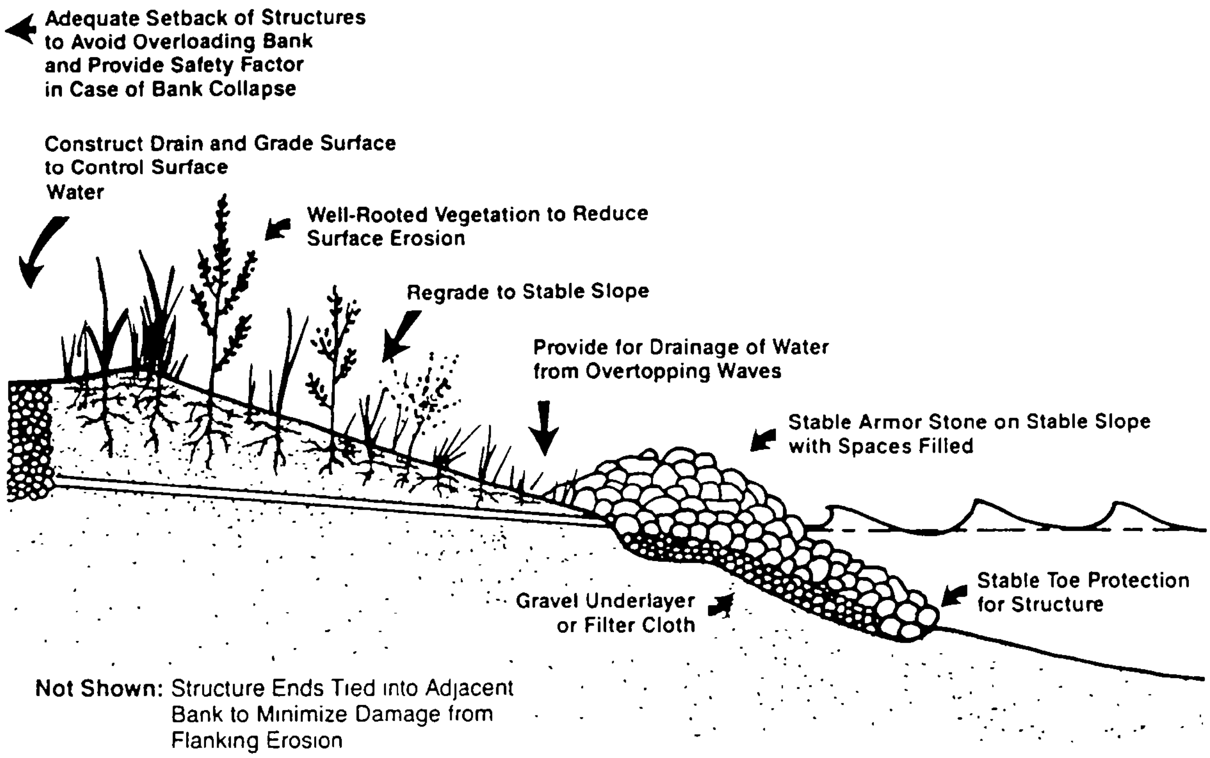

Figure 14. Example of Well-Designed Project (Univ. Wisconsin Sea Grant, 1987).

a. Site Characteristics. Ramps are generally constructed in areas where there is fairly deep water close to shore, and where there is some protection from waves. Boat ramps should be located in areas where they will not interrupt the longshore movement of sand, since this may lead to an accumulation of sand on the updrift side and erosion on the downdrift side. Ramps should not be built in marsh areas.

b. Environmental Consequences. The greatest impacts of launch ramps are generally due to the activities associated with the structures, not the structures themselves. This includes increased boat traffic, channel dredging, parking facilities, and increased human usage. Boats cause wakes which can increase shoreline erosion and can damage shallow beds of submerged aquatic vegetation. Boating activities and noise can also disturb wildlife and nesting birds. Parking facilities can cause runoff of contaminated rainwater if not properly designed, and trash and debris will often accompany the increased human use.

c. Human Shoreline Use. Boat ramps will provide access to the shoreline and the water body. This can allow increased enjoyment and appreciation of an estuary, but it can also create additional noise and traffic.

d. Design Considerations. The following recommendations are for heavily used public launching facilities. Private boat launching ramps will typically be less elaborate.

(1) Public launching ramp lanes should be 15 feet wide on ramps of two or more lanes. If the launching ramp consists of a single lane it is recommended that the lane be 20 feet wide, and never less than 16 feet wide. One

launching lane will handle approximately 50 launchings and 50 retrievals per day.

(2) A vertical curve should be incorporated into the head of the ramp to provide a smooth transition between the launching ramp and the parking area. The curve keeps trailer hitches from striking the launching ramp at a change in grade, and enhances the driver's vision while backing. A 15- to 20-foot radius vertical curve is recommended.

(3) Concrete is most commonly used for the construction of heavily used launching ramps. Concrete should have a minimum of 3 inches of cover over rebar. Precast concrete planks should be designed to bolt, cable, or key together during installation to prevent movement. Cast-in-place concrete ramps should be finished with V-grooves aligned at 60 degrees to the longitudinal axis of the ramp. This provides traction on slick marine growth and aids in cleaning the ramp.

(4) In areas subject to currents or waves, the ramps must be protected by a 3- to 5-foot perimeter of riprap or other means of scour protection.

(5) Where possible, parking areas should be located immediately adjacent to the launching ramp. Parking areas should be built on upland grounds, not filled intertidal areas. Stormwater runoff from launch approaches and parking areas should be filtered through sand or vegetated areas and should not be directed down the boat ramp.

(6) Garbage receptacles for marine trash should be provided as close to the launching ramp as practical.

(7) Some organizations have instituted public awareness campaigns at public boat ramps, informing the boating public of environmental impacts of boating on submerged aquatic vegetation, bank erosion, and litter, and recommending practices to minimize boating impacts.

e. Cumulative Effects. The construction of ramps will cover a limited intertidal area, creating a minimal impact from construction alone. The major impacts will be due to the increased human use, boat traffic, and associated effects.

f. Regional Considerations. Heavily developed areas will see much more of an impact due to boat ramps than lightly developed or isolated areas. Areas with shallow water and submerged aquatic vegetation will be more affected by boat damage.

Piers and Pilings

Piers are structures designed to provide access from the shoreline to deep water. Piers can be supported on pilings or can be floating and are used for a variety of functions in estuaries, such as mooring boats, fishing, supporting aids to navigation and signs, and supporting other structures such as bridges.

a. Site Characteristics. Piers are built on a wide variety of sites and shoreline types. They are suitable for most bottom conditions. The length of pier will be governed by the distance from shore to deep water. Fixed piers are used under a wide range of tidal conditions, but floating piers offer more convenient access to boats in areas where tides exceed several feet.

b. Environmental Consequences. Piers and pilings cover a relatively small area of the bottom and hence are generally not as damaging to the environment as solid fill structures. Construction and pile driving can cause temporary suspended sediments. Extensive groups of closely placed pilings can alter currents and sedimentation patterns. Pilings should be kept as widely spaced as possible to minimize this effect. The major impact of piers is due to shading of the bottom, reducing the productivity of submerged vegetation. Some regions require that piers be elevated at least one foot above the bottom for each one foot of deck width to minimize shading. A 1-inch spacing between deck boards can also increase the available light under the pier. Wood treated with creosote is discouraged because of its possible impact on marine life. Access to piers through marsh areas should be by elevated walkway to minimize damage to the plant life due to traffic.

Floating piers can cause a greater impact on sediment transport and deposition, and should be avoided in areas of large transport. Floating piers will also cause a greater shading in shallow water since they are closer to the

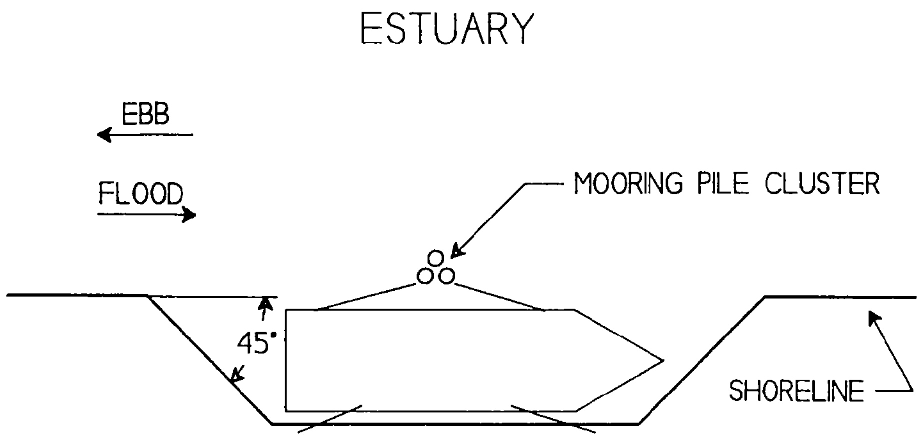

Figure 15. Indented Boatslip.

bottom. Often fixed piers can be used at the shoreline to minimize these problems, with floating piers used at the seaward end in deeper water.

c. Human Shoreline Use. Piers can attract the same increased human use as boat ramps. This should be considered when planning construction of a pier. Impacts include parking problems and contaminated runoff from parking lots, litter, increased boat traffic, and increased foot traffic. Public piers should be handicapped accessible.

d. Design Considerations. Piers and piling design should be based on local conditions, including water depth, the wave and tide environment, and geotechnical conditions. Local knowledge will often be the best guide for small private facilities. Larger facilities will require the services of an engineer who will conduct proper geotechnical investigations as part of the design process to determine pile sizes and embedment depths.

Piers should not obstruct boat traffic or create hazards to navigation. Piers, including the width of the boat moored at the end, should not extend more than 1/4 of the way across the water body.

All piers should have safety rails which meet the applicable local construction codes.

e. Expected Lifespan. Pilings of wood, concrete or steel generally will have a lifespan of 30 years if properly treated and maintained. Certain conditions, such as high salinity and high temperatures, can shorten the lives of pilings. Marine boring organisms can quickly destroy wood which is not properly treated.

f. Cumulative Effects. Cumulative effects of piers and pilings will be caused by increased human use accompanying their construction and in areas of dense construction due to shading of the bottom. These effects can be minimized by keeping piers as narrow as possible and by joint use of a single pier instead of a number of individual piers.

Boat Mooring Slips

Many property owners choose to moor their boats by creating a boat slip from the upland portions of their property in regions where this is permitted. In the past, boat slips were dredged deep into the upland property creating a square or rectangular boat slip with upland on three sides. This type boat slip exhibits poor water quality conditions because of the lack of flushing. This type of boat slip is no longer permitted in many coastal areas. A new type of boat slip (shown in Figure 15) is now being constructed along the coast, with the slip parallel to the shoreline and sides angled to allow better water flow.

Other areas do not allow any dredging of uplands to create boat slips. In these areas, boats are moored on piers constructed to deep water.

a. Site Characteristics. Boat slips are dredged into banks which front deep water, so that access channel dredging is minimal. No dredging through marsh areas is allowable.

b. Environmental Consequences. The impact of the boat mooring slips includes suspended sediments and destroyed nearshore and intertidal habitats during construction. If the boat mooring is not properly designed so that water circulation takes place, the water quality will be degraded within the slip. The sides of the boat slip must be properly stabilized with vegetation or riprap to prevent continuing erosion and suspended sediment loads.

c. Human Shoreline Use. The dredged mooring slip allows individual property owners to moor their boats on their property, increasing the convenience and enjoyment of owning the boat.

d. Cumulative Effects. A large number of dredged boat slips will alter a portion of the shoreline from the natural nearshore and intertidal habitat to a deeper dredged bottom and steeper bank. The practice may also encourage increased boating in nearshore shallow water, as opposed to the deeper water near commercial marinas, piers, or public boat ramps.

e. Regional Considerations. The regulations governing dredged boat slips varies from state to state. Not all states allow individuals to dredge boat slips into upland areas.

Boat Houses

Often there is a need to protect moored boats from the weather. In these cases boat houses are constructed over the mooring area. In addition to a weatherproof roof, many Boats are hoisted out of the water for additional protection. A typical boat house is shown in Figures 16 and 17.

a. Site Characteristics. Boat houses are built in the same general type of sites and have many of the same impacts as piers. Sites generally consist of those with navigable depths of water near shore.

b. Environmental Considerations. Environmental effects are also generally the same as piers. Shading of vegetation is of greater concern because of the larger area of the roof. This can be minimized by leaving the sides of the structure open and keeping walkways narrow to allow as much light as possible on the bottom. Keeping the boat out of the water when not in use will help eliminate some of the impacts of boats on the environment, such as the degradation of toxic bottom coatings and leaking of petroleum products.

c. Human Shoreline Use. Boat houses are for the convenience of the boat owners. They should not be allowed to become obtrusive or block access along public shorelines. Boat houses can be kept less obtrusive by keeping the sides open and by keeping them as close to the shoreline as possible.

d. Cumulative Effects. The environmental effects of boat houses and the techniques for minimizing those effects are similar to those of piers as described in Section 4.

SHORELINE HABITAT REHABILITATION

Loss of nearshore habitat has been associated with the loss of fishery productivity of estuaries. This has primarily been due to the construction of bulkheads and fill in marsh areas. Some organizations are attempting to reverse this situation by improving nearshore habitat along bulkheads and revetments. The use of artificial reefs as fishery habitat has become popular in some areas of the Southeast. Until recently, this habitat creation has been restricted to deep water and the enhancement of adult fish populations. Shoreline habitat rehabilitation aims to create nursery habitat for young fish. There are a number of methods available to "soften" developed shorelines and return them to a more natural state. Some of the most promising are discussed below. For the most part, they are similar to recommended minimal impact shoreline erosion protection methods, with similar impacts and benefits.

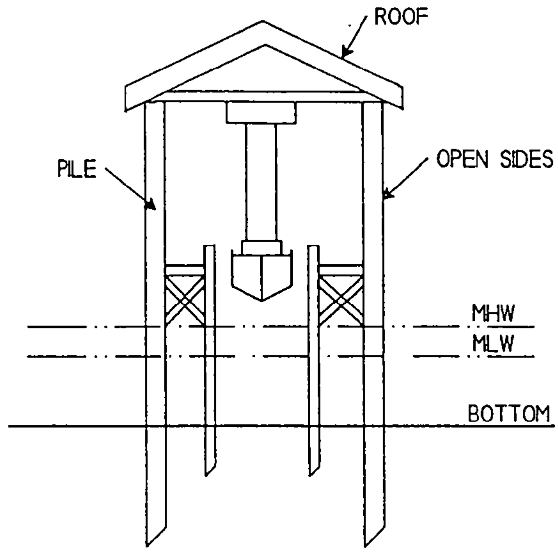

Figure 16. Boat House Section.

Vegetation

a. Site Characteristics. Vegetation will enhance the nearshore habitat in any areas where it can survive. The requirements for the survival of vegetation in the intertidal zone were discussed in Section 4. Many sites with bulkheads or revetments with toes above MLW will be suitable for the establishment of vegetation, either with or without the removal of the structure. Other areas can be made suitable with stone sills and fill.

b. Environmental Consequences. The re-establishment of nearshore vegetation provides a protected area of shallow water with cover from both aquatic and bird predators. The vegetation also provides a food source for a wide variety of aquatic life, which in turn provides a food source for fish. As discussed previously, vegetation can also filter runoff into an estuary, improving overall water quality.

c. Design, Cost, and Lifespan will be the same as described for a vegetated shoreline erosion control project in Section 4.

Toe Stone and Sills

a. Site Characteristics. Many sites which will not be suitable for vegetation because of depth or wave action can be improved by the application of stone along the toe of vertical structures. Any bulkhead that is an adequate distance from a navigable waterway is a candidate for toe stone. Other areas could be improved by a sill built seaward of a bulkhead or revetment, with fill supporting vegetation planted behind the sill. Although deep water seaward of a bulkhead will make the cost of this alternative greater, there is no limit on water depth with this alternative.

b. Environmental Consequences. The application of stone riprap at the toe of a bulkhead replaces a deep water habitat subject to scour during storm events with a shallow, stable nearshore environment. The voids and surfaces of a stone surface provide habitat to a wide variety of marine life and improve the habitat for juvenile fish.

c. Design, Cost, and Lifespan considerations for sills and toe stone are the same as those described in Section 4. Toe stone will also improve the performance of a bulkhead by preventing toe erosion and reducing runup and over-topping during storms.

Figure 17. Constructed Boat House.

Artificial Reefs

a. Site Characteristics. In many developed estuaries, the bulkheaded canals formed by dredging and filling of marshland are the least productive areas. The canals are too deep to provide shallow habitat and too narrow for extensive toe stone or other "natural" habitat enhancement alternatives. Artificial reefs are structures designed specifically for placement at the toe of bulkheads to attract and support juvenile fish species.

b. Environmental Consequences. The structures have been designed to be lightweight and easily placed and will attract a variety of marine life and provide shelter for young fish. These structures are largely untested, although there is currently one project as part of the Sarasota Bay National Estuary Program evaluating a variety of designs for effectiveness, lifespan, and stability.

c. Design Considerations. Regulatory agencies are currently reluctant to allow large scale private placement of materials in shallow water for habitat enhancement due to concerns about navigation, shifting or drifting of unstable structures, leaching of pollutants from unsuitable materials, and esthetics. Permits are required for such work, just as they are required for all other types of fills in estuaries.

5.0 CONCLUSIONS

ENVIRONMENTAL IMPACTS

Construction along the shoreline of estuaries for erosion control or shoreline access will have a variety of impacts on the environment, often causing a loss of habitat and reduced productivity of marine life. The cumulative effect of a large number of small individual projects can have a major impact on the estuary as a whole. This cumulative development has drastically reduced the water quality in some of the more heavily developed estuaries in the southeast United States in the last 40 years. Many other estuaries are currently undergoing rapid development, with the potential for loss of recreational and commercial fisheries, loss of habitat for wildlife and waterfowl, degradation of water quality, and spoiling the beauty of the shoreline. A photograph of a shore protection project that is under construction is presented in Figure 18.

These effects can be minimized by proper planning and construction of shoreline structures. In many cases the shoreline environment can be improved by incorporating the best practices of shoreline erosion control. Each local shoreline development project has the potential to either improve conditions or degrade the environment further.

Table 2 is a Shoreline Development Impact Matrix which provides information on the relative impact on the estuarine environment of various types of shoreline development. This matrix can be used to help choose the shoreline development with the least impact to the environment. This figure presents the negative and positive impacts of each of the shoreline erosion control and shoreline access options discussed in Section 3. Each option is evaluated in terms of habitat loss (either dredging or filling), effects on nearshore circulation, causing or improving scour of the bottom or sedimentation along the shoreline, runoff from upland areas, shading of vegetation, and the visual impact of the shoreline when viewed from the water. The evaluation is somewhat subjective and will vary greatly from project to project, but the matrix provides a general guide to shoreline development impacts on the environment.

There are a number of other elements in choosing an optimal shoreline development structure, or evaluating a development's total impact. Another important consideration is summarized in Table 3, the Shoreline Human Use Impact Matrix. Human use impacts are related to how a development affects the recreational use of the shoreline and how the human use impacts the environment. The human use impact of each of the shoreline development options is summarized in terms of boating, swimming, fishing, walking along the shoreline, viewing the shoreline. Impacts can vary greatly depending on the intensity of the human use. For instance, a single homeowner may have minimal impact walking along and fishing from a vegetated shoreline; but if the same shoreline is accessible to the public, vegetation may soon be destroyed.

The third element affecting the choice of shoreline erosion control is the type of shoreline. Shorelines can consist of a variety of different types, including marshes, beaches, banks and bluffs. Some erosion control methods will be more applicable to certain shoreline types than others. Table 4 summarizes the suitability of the shoreline erosion control methods to the various shoreline types.

Other factors which enter into the selection of a suitable erosion control method for a particular situation include the length of open water to which a site is exposed (fetch length), which affects wave conditions, the range of water levels at the site under normal and storm conditions, the angle at which the waves strike the shoreline under storm conditions, and the cost of the options. These factors are summarized in Table 5, the Shoreline Erosion Control Selection Matrix.

COMBINED TECHNIQUES

Examination of the shoreline erosion control impact and selection matrices shows that there is often a conflict between the best environmental erosion control solution and the desired human use of the area. For instance, vegetation

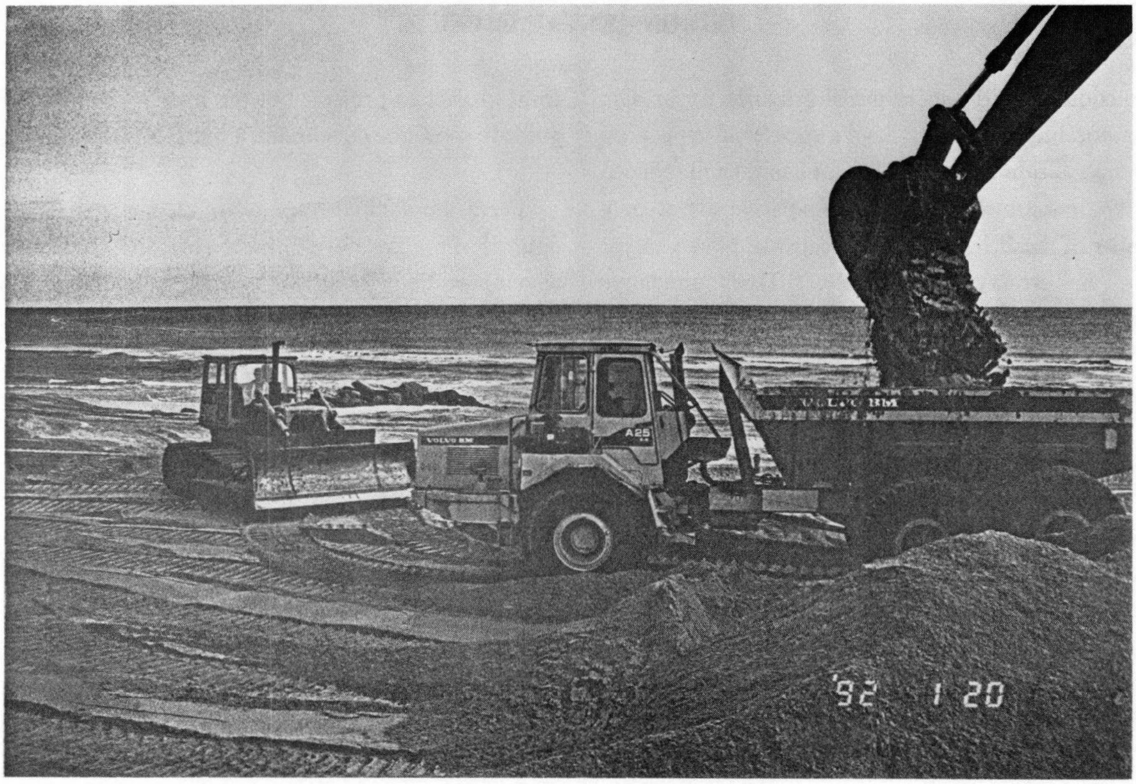

Figure 18. Construction Activities Along a Shoreline.

erosion control is in general the preferred option for the environment in areas where it will work, but a vegetated shoreline precludes intensive use of the shoreline for walking, swimming, boating, etc. By combining two or more shoreline erosion control methods, the environmental benefits of the best methods can be achieved while still providing the desired human use. This might be done by using vegetation or a sill with vegetation for most of a shoreline, but then providing a small swimming beach confined by groins or breakwaters. A beach can also provide a shoreline suitable for landing small boats, walking, etc.

A combined method may also be the best option when there are a variety of shoreline types in a single area or when one portion of the shoreline requires substantial wave protection because of adjacent structures, while other areas of the same shoreline can be allowed to erode slightly in major storms. An example is shown in Figure 19.

Figure 19 shows a shoreline where extensive eroding has been ongoing. At the northern end of the property there is a series of eroding marsh headlands separated by small pockets of sand seaward of an eroding bank. The southern end of the property turns toward the west with a different exposure. A roadway is threatened by the shore erosion process.

The figure shows the proposed shoreline erosion control method. Low sills with sand fill and marsh plantings are recommended for the northern end of the property. The sills will stabilize the eroding scarp of the marsh headlands and also help confine the sand fill within the sand pockets. Sand fill and marsh plantings will help stabilize the banks landward of the beach. The marsh grass at the upper slopes

Table 2. Shoreline Development Impact Matrix.

SHORELINE DEVELOPMENT	Habitat Loss	Circulation Effects	Scour and Sediment	Runoff	Vegetation Shading	Visual Impact
Vegetation	●	○	○	●	—	●
Sills and Reefs	○	○	—	●	—	○
Beach Fill	□	—	○	—	—	○
Breakwaters	□	○	○	—	—	□
Revetments	□	□	□	■	—	□
Groins	□	■	■	—	—	□
Bulkheads	■	■	■	■	□	□
Launch Ramps	□	□	□	■	—	□
Piers and Pilings	—	—	□	—	■	■
Mooring Slips	■	■	□	—	—	■
Boat Houses	—	—	□	—	■	■

MATRIX KEY:
● Beneficial Impact
○ Minor Benefit
— No Impact
□ Minor Negative Impact
■ Major Negative Impact

of the beach will help prevent the sand fill from being carried landward over the existing bank during storm conditions. A low continuous sill is recommended for the marsh at the southern end of the project. This sill will stabilize the erosion of the front edge of the marsh, preventing additional erosion while preserving the benefits of a marsh. The sill is low and porous enough that it will not prevent flooding of the marsh or movement of marine life into and out of the marsh.

This design is economical, environmentally desirable, and provides a range of human use alternatives. It combines marsh vegetation, bank grading, bank vegetation, and sand fill. All runoff from the roadway is filtered through sand or vegetation and a large amount of new marsh is created. Each shoreline must be evaluated based on the shoreline characteristics, wave and water level conditions, and needs of the owner; but it is often possible to combine a number of alternatives to create the optimal shoreline erosion control plan.

Table 3. Shoreline Human Use Impact Matrix.

SHORELINE DEVELOPMENT	Boating	Swimming	Fishing	Walking	Viewing
Vegetation	■	□	□	□	●
Sills and Reefs	■	□	□	□	●
Beach Fill	●	●	○	●	○
Breakwaters	○	○	●	—	—
Revetments	□	□	○	□	—
Groins	□	○	●	□	—
Bulkheads	●	●	□	○	□
Launch Ramps	●	■	○	□	■
Piers and Pilings	●	○	●	□	■
Mooring Slips	●	□	—	□	□
Boat Houses	●	○	□	□	■

MATRIX KEY:
● Compatible
○ Somewhat Compatible
— No Impact
□ Somewhat Not Compatible
■ Not Compatible

PROFESSIONAL GUIDANCE

Minimizing the environmental effects of shoreline development can be complex, with a wide variety of factors entering into each shoreline erosion control or shoreline access plan. It will generally be beneficial to obtain guidance from experts in the field. Assistance can be provided by governmental agencies involved in protecting the environment and providing permits for shoreline development. This includes U.S. Government agencies such as the Environmental Protection Agency, the Army Corps of Engineers, and the Fish and Wildlife Service; State departments such as the appropriate environmental protection agency and natural resource agency; and local departments such as city or county permitting, planning, and zoning agencies.

All construction in estuarine waters will require a permit, and obtaining information on local requirements before planning is complete can save considerable time due to plan revisions and adjustments. Coastal engineers, environmental consultants, experts from local universities, and local contractors can all provide information based on local knowledge and experience.

Table 4. Shoreline Erosion Control Applicability Matrix.

SHORELINE EROSION CONTROL TYPE	Marshes	Beaches	Low Banks	High Banks	Bluffs
Vegetation	●	○	—	—	—
Sills and Reefs	○	—	—	—	—
Beach Fill	□	●	—	□	□
Breakwaters	—	●	○	○	—
Revetments	□	—	●	●	●
Groins	■	●	—	—	□
Bulkheads	■	□	●	○	—
Drainage Controls	■	□	—	○	●
Slope Flattening	■	■	○	●	—
Relocation	—	—	—	—	—
No Action	□	□	□	□	□

MATRIX KEY: ● Almost Always Applicable
○ Usually
— Sometimes
□ Rarely
■ Almost Never Applicable

Table 5. Shoreline Erosion Control Selection Matrix.

SHORELINE EROSION CONTROL TYPE	Fetch Length	Water Level	Wave Length	Relative Cost
Vegetation	< 1 Mile	Any	Any	Low
Sills and Reefs	<5 Miles	Any	Any	Low
Beach Fill	Any	Medium	Low	Moderate
Breakwaters	Any	Any	Any	High
Revetments	Any	Any	Any	High
Groins	Any	Any	Low	Moderate
Bulkheads	Any	Medium	Any	High

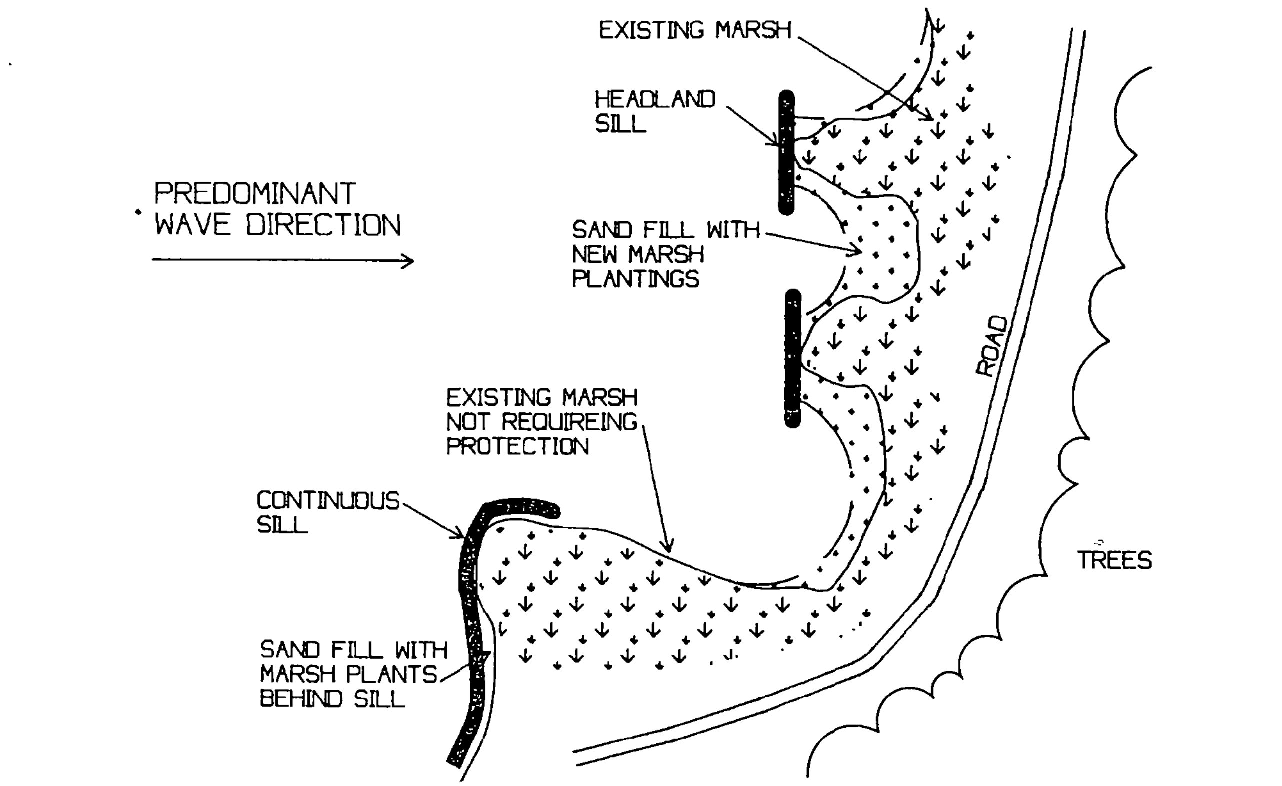

Figure 19. Plan View of a Sample Shore Erosion Control Project.

6.0 APPENDIX: ADDITIONAL INFORMATION

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