Shoreline Erosion Guidance For Chesapeake Bay: Virginia

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I. Introduction

The tidal shorelines of the Chesapeake Bay estuarine system are an important resource. The land, water, and air interface defines the wetted perimeter where land use and clearing practices have, since colonial times, often taken on an adversarial role with regard to the conservation/management of marine resources. With groundwater seepage, the rise and fall of the tide, wave action from storms and rain generated surface runoff, the shoreline is in a state of constant change.

The most active changes occur where wave action against the shore is most intense. Shoreline erosion and accretion are the result of this wave activity; the local wave climate. The highest rates of shoreline erosion occur along the shorelines of the main stem of the Chesapeake Bay where the fetch exposures are the greatest.

The purpose of this chapter is to describe and illustrate the geological processes and physical evolution of Chesapeake Bay and its tidal shorelines and the relative impacts of the strategies that are employed to abate shoreline erosion. Included in the discussion will be the role of marshes, beaches, dune systems, and sea level rise in shoreline evolution and shoreline erosion. Shoreline erosion treatment methods include but are not limited to: bulkheads, stone revetments, groins, beach nourishment, breakwaters, the establishment of marsh fringes, and/or any combination of the foregoing.

Over the years landuse conversion along the rivers, creeks and bays has been predominantly woodland to agricultural with pockets of residential development ever increasing (Hardaway et al. 1992). Waterfront property values have increased and control of shoreline erosion has become expensive. Traditional methods or strategies to abate shoreline erosion include the use of wood bulkheads and groins as well as stone revetments. More recently the use of beach fill, marsh grasses and offshore breakwaters and sills has increased for a variety of reasons including environmental, financial and social preferences.

Addressing shore erosion has often been done in a haphazard fashion without a basic understanding of the temporal and spatial parameters involved. It is at this point that we find ourselves needing to provide a framework from which to assess what is being done along the shorelines of the Commonwealth with an eye toward water quality and habitat preservation as well as coastal hazards and property loss.

II. Shoreline Evolution (History)

Management of Virginia's Chesapeake Bay shorelines needs to start with a detailed understanding of how today's shorelines have reached their present state. The Chesapeake Bay and its tributaries are drowned river valleys of the ancestral Susquehanna River system (Figure 1). The Chesapeake Bay estuarine system is a geologically young portion of the Virginia coastal system with over 5,000 miles of tidal shoreline.

It is important to understand that the long term driving process affecting the shore zone and shoreline erosion is the slow rise in sea level. About 15,000 years ago the ocean coast of Virginia was about 60 miles to the east of its present location and sea level was about 300 feet lower. The coastal plain of Virginia was broad and low. The estuarine system was a meandering series of rivers working their way to the coast. As sea level rose these fluvial systems (rivers) were inundated and the shorelines receded. This recession, often called shoreline erosion, was accelerated by the seasonal occurrence of storms such as northeasters and the occasional hurricane. Today, relative sea level continues to rise and it is still the storm events that cause the greatest changes along the estuarine and ocean shorelines.

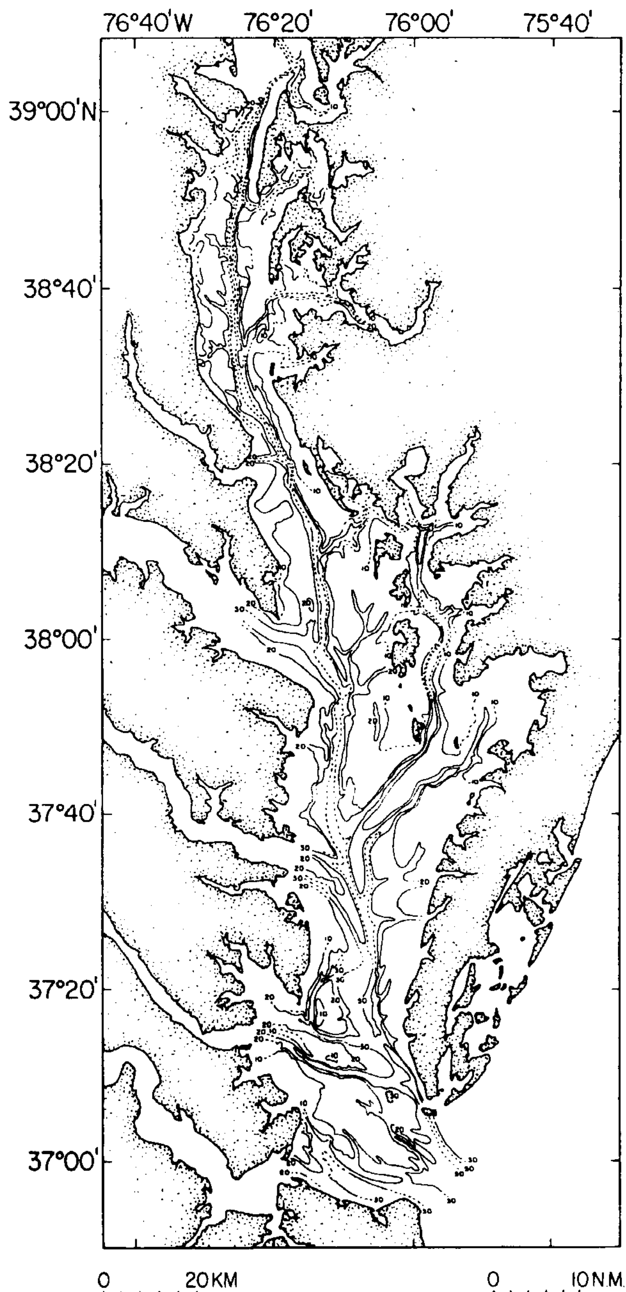

FIGURE 1. Map showing the Chesapeake Bay today with the ancestral Susquehanna drainage.

The major shore types associated with the latest oceanic transgression include marsh and upland banks and to a lesser extent dunes, beaches and spits. The marshes occupy the fringes of watersheds and low regions of the coastal system in front of, or bayward of, upland regions. Marshes and their associated peat substrates are important geomorphic features. Marshes grow vertically and laterally landward in response to sea level rise. The shoreline of the marsh will erode in response to wave action but will also protect the upland areas from the same erosive forces.

As shoreline recession continues, fetch exposures increase and the potential wave energy impacting a given shoreline increases as well. If the rate of marsh shore erosion exceeds the rate of lateral and vertical landward movement, then the marsh will eventually become too thin or non-existent and unable to protect the upland region. The upland then becomes exposed to wave action and begins to erode. Erosion of upland banks then provides additional sediment into the estuarine system helping create beaches and spits. Wetland and upland vegetation may colonize these newly created substrates helping stabilize the unconsolidated sediments.

Nearshore regions also evolve with time. The position of tidal flats, offshore sand bars and shoals are a function of shoreline erosion patterns, wave climate, sediment supply and tidal currents. Nearshore depth or bathymetry is a critical parameter in wave attenuation. Wave action can be significantly reduced across shallow flats and sand bars.

The underlying geology is the major factor in the height and composition of eroding upland banks, the position and extent of marshes define the areas more prone to tidal flooding. One major defining coastal feature called the Suffolk Scarp runs the length of the Virginia Coastal plain along the west side of Chesapeake Bay (Figure 2, page 4). The Suffolk Scarp is an old beach feature, formed during a high stand in sea level approximately 2 million years ago (Pleistocene epoch).

West of the Suffolk Scarp the shoreline banks rise to heights of 25 to 50 feet. Other scarps to the west, like the Surry Scarp, cause the land and shoreline banks to rise even higher (70 to 100 ft) as is the case with Nomini Cliffs in Westmoreland County. East of the Suffolk Scarp the land drops to areas that may be less that 5 ft above sea level. Extensive marshes occupy the lowland drainages. These areas include much of the Bay fronting shoreline of the cities of Norfolk, Hampton and Poquoson as well as York, Gloucester, Mathews and Middlesex counties.

The Eastern Shore of Virginia is a geologic feature that was created by progressive sedimentation at the distal end of the Delmarva Peninsula. The bay side of the Eastern Shore has experienced a similar shoreline evolution sequence. Large expanses of embayed tidal marsh occur in and around Pocomoke Sound. As one proceeds south along the bayside shoreline, the land rises around Onancock Creek to expose eroding sandy upland banks. Eroding upland necks of the southern Eastern Shore provide large amounts of sediments to adjacent downdrift shorelines and help supply extensive offshore bar systems.

Added to the general evolutionary pattern of Chesapeake Bay shorelines are the many sub-estuaries more commonly known as tidal creeks. These are an integral component of the Bay's flooded dendritic watershed. These creeks are of varying size and where they enter the Bay or major estuary there is often an impact to littoral processes and shoreline evolution in the form of flood and ebb shoaling. This shoaling often restricts navigation and dredging or jetties are required to maintain the desired channel. Adjacent shorelines are usually directly affected by these measures, either by sand accretion or sand deprivation and consequent shoreline erosion.

The impact of shoreline protection installations on the recent shoreline evolution process is several fold. First of all, the eroding sediment banks that had provided sands for beaches, spits and offshore bars are removed by erosion protection measures. The once eroding bank no longer supplies its "natural" input of sand. Secondly, since the protected shoreline does not erode, at least for several years, the impinging wave climate is altered by wave reflection. This is especially true for defensive structures like bulkheads and seawalls. The sloped face of a rock revetment tends to reduce reflection but it may still occur.

Wave reflection can increase the loss of existing beaches and marsh features immediately seaward of shoreline protection structures. As well, the combination of beach loss and increased nearshore depth may allow increased impinging wave heights and increase the potential for bottom scour and shoreline retreat. Protected segments of shoreline can remain essentially as hard points or headland features while adjacent unprotected properties continue to erode sometimes at an accelerated rate.

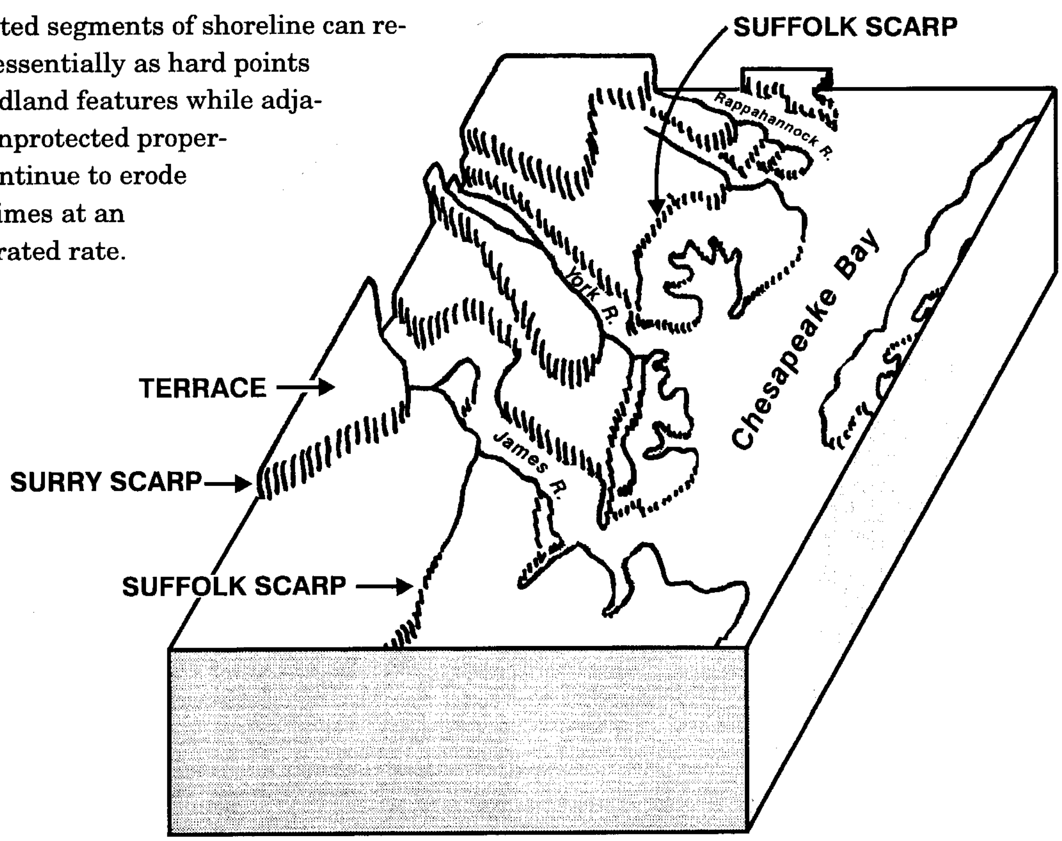

FIGURE 2. Ancient scarp features of the Virginia Coastal Plain. (After Pebbles, 1984)

III. Shoreline Erosion Processes

A. Wave Climate

Shoreline erosion on a daily basis is on average minimal. Severe erosion occurs during periods of high energy storms such as northeasters and hurricanes during which high winds blow across the Bay and generate increased wave conditions . Therefore, the rate of erosion at any specific location depends upon the following conditions (Riggs et al. 1978):

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

Seasonal wind patterns vary in the Chesapeake Bay region. From late fall to spring the dominant wind direction is from the north and northwest. During the late spring, the dominant wind shifts to the southwest and continues so until the following fall. Northeast storms which occur from late fall to early spring are associated with eastward moving storm fronts. Frequently, there is a period of intense north to northwest wind following the passage of the front. Hurricanes, with sustained winds of at least 74 mph, can occur from midsummer to mid-fall. Although they generally have higher winds and storm surge, they will often pass a given region faster than a northeaster.

The wave climate impacting a particular shoreline along the Chesapeake Bay estuarine system is dependent upon numerous factors including fetch exposure, shore orientation, shore type and nearshore bathymetry. Fetch is defined as the distance of open water over which wind can blow and generate waves. In Chesapeake Bay, the wave climate is both fetch-limited and depth-limited.

Fetch exposure and water depth can be used as simple measures of relative wave energy in the Bay. Hardaway et al. (1984) categorized relative potential wave energy acting on a given shore reach into three general categories based on average fetch exposure.

1. Low energy shorelines have average fetch exposures of less than 1 nautical mile (nm). These are generally found along tidal creeks and smaller tributary rivers.
2. Medium energy shorelines occur mostly along the main tributary estuaries and have average fetch exposure of 1 to 5 nm.
3. High energy shorelines are adjacent to the main stem of the Bay and the mouths of the tributary estuaries with average fetch exposures of over 5 nm.

Storm surge is another critical element for consideration in determining local wave climate. In the lower Chesapeake Bay storm surges for a 10 yr, 25 yr, 50 yr and 100 yr storm are 4.5 ft, 4.8 ft, 5.5 ft and 6.1 ft mean sea level (MSL) (Boon et al. 1978). According to Basco, 1993, wave heights during moderate northeast storm conditions (every 2 years) with sustained winds of 30 to 40 mph can be 5 ft to 8 ft in the Bay (high), 2 ft to 5 ft in the main tributary estuaries (medium) and about 1 ft in small tidal creeks (low).

B. Shoreline Erosion

There are over 5,000 miles of tidal shoreline in the Commonwealth of Virginia (Byrne and Anderson, 1978). Land loss to shoreline erosion since 1850 amounts to over 40,000 acres. Some of the most dramatic shore erosion losses occur along the Bay main stem where fetch exposures and impinging waves are highest. Figure 3 is an example of a Bay shoreline-change map for southeast Mathews County. Of note is the 1852 shoreline, showing the marsh islands along Chesapeake Bay and the extent of New Point Comfort at that time.

The fastland or upland areas adjacent to the estuarine shorelines of Chesapeake Bay vary in height and composition. They come under direct wave attack when shore zone features such as beaches, fringing marsh and beach/dune systems are absent or not wide enough to offer protection. The shore zone features themselves are either eroding, stable or accreting. These features may protect upland properties during annual storm events but may not adequately protect during lower frequency but more severe storms (i.e. 10, 25, 50 or 100 year events).

For the purpose of this discussion, the tidal shorelines of the Commonwealth

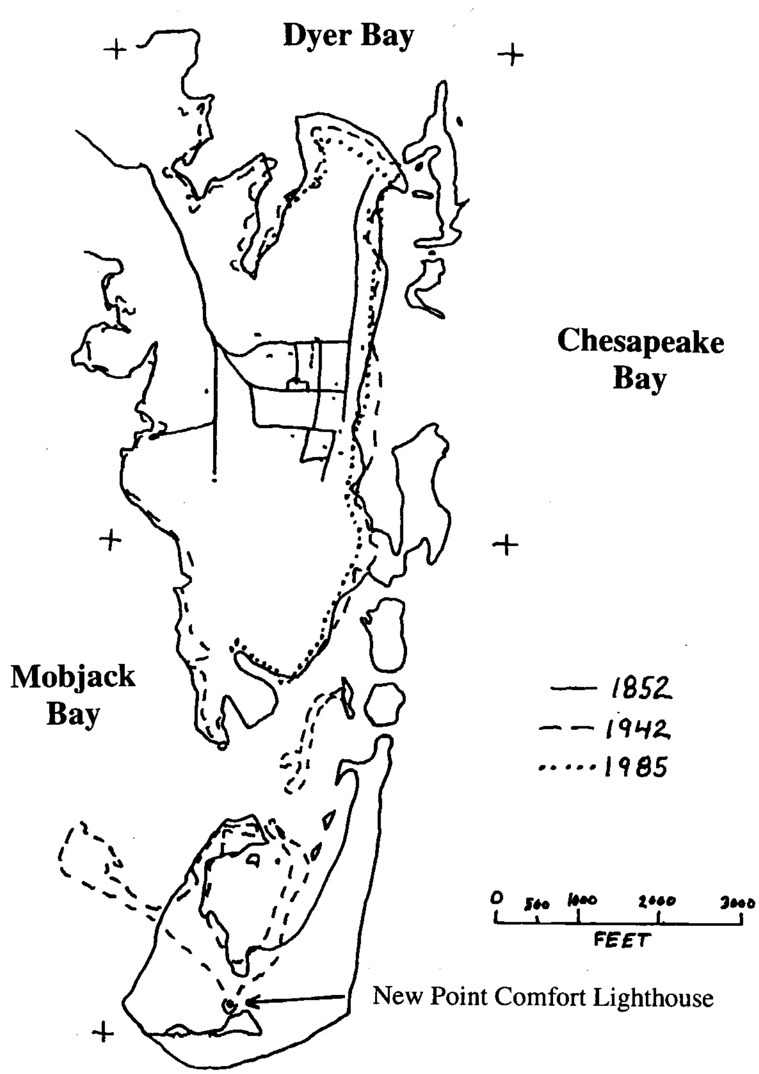

FIGURE 3. Historic shoreline change in southeast Mathews County. (VIMS Shoreline Studies)

are classed into six basic types (Figure 4, page 8). This classification, after Hardaway and Byrne, (1996), is based on fastland bank height where there is a high and low bank situation. The high bank is any fastland elevation greater than 10 ft above mean low water (MLW) and the low bank is any fastland 10 ft above mean low water (MLW) or less. The rationale for this is that low fastland banks will be potentially susceptible to frequent flooding whereas the high banks will not. Wave attack on low banks may occur landward of the top of the bank where property improvements may be directly threatened by storm surge and wave action. Property improvements on high bank situations will not be impacted directly by storm surge or wave action. However, if the improvements are near the edge of the bank, bank erosion and slumping from wave undercutting may pose a threat.

Shore zone features will vary in type and width depending on the particular shore setting. This will in turn determine the bank face stability and the potential need to protect the bank from erosion. Wide fringing marshes, beaches and dunes will attenuate wave action during storms and upland banks may only be impacted by the most severe events (i.e. 100 yr storm). Narrow shore zone features will allow more frequent wave impact to the upland banks, causing chronic instability and continual erosion. There are various combinations of these six situations and they will occur adjacent to each other and will change through time.

Fetch exposure and the present condition of any given shoreline situation will dictate what shoreline protection measure can be reasonably employed. The landowner's desires and funding resources are also a factor. Building shoreline protection structures to completely stop upland wave attack is usually not feasible along low bank situations where the storm surges overtop the fastland. However, emplacing a shore protection system that will withstand the waves and storm surge as well as remain intact after a severe storm is quite feasible. These factors must be considered in the design phase of any shoreline strategy.

IV. Reach Assessment

Before any shoreline management strategy can be implemented, a site assessment should be performed. This may not be possible for all local wetlands board actions but knowing the basic elements involved should prove helpful in understanding the scope of such an evaluation. This task should be performed to some degree by the landowner or agent. Technical assessment of a reach involves six principal elements:

1. Determination of the limits of the **reach** the project lies in. A reach is defined as a segment of shoreline wherein the erosion processes and responses are mutually interactive. For example, appreciable littoral sand would not pass the boundaries of a reach. Reach boundaries may include major points of land, creek mouths or changes in shoreline orientation.
2. Determination of the historical rates and patterns of erosion and accretion for the reach. Identify shore types (i.e. upland banks and marsh) and their impact to shoreline processes and shoreline evolution.

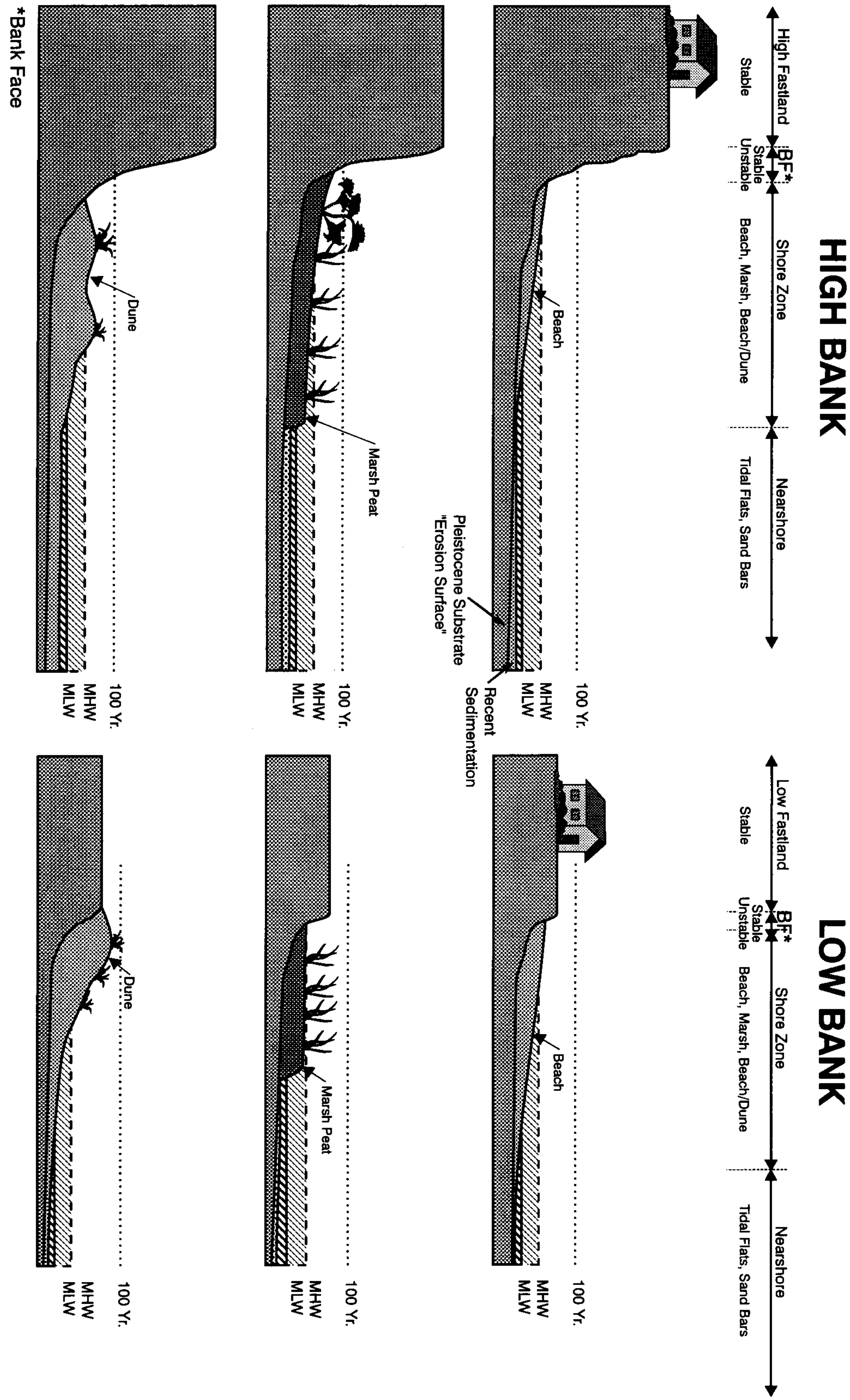

FIGURE 4. Six typical shoreline profiles around Chesapeake Bay. The stability of the bank face is dependent upon the the width and type of shore zone features. (After Hardaway and Byrne, 1996)

3. Determination within the reach of the sites of the induced sand supply and the volume of that sand supply for incremental erosion distances. Often there are interactive subreaches which are regions of sediment source (erosion), sediment transport and/or sediment accumulation (accretion).
4. Determination of effective wave climate and the direction of net littoral drift as well as a reasonable estimation of potential impacts for a proposed project on adjacent shore zones.
5. Estimation of erosion causing factors other than wave induced, such as groundwater or surface runoff.
6. Estimation of potential and active sources of nutrient loading (i.e. farmland or residential land) and the pathways by which this occurs such as by surface runoff, eroding sediments and/or groundwater discharge.

V. Shoreline Strategies

Revetments, bulkheads and groins are the most common shoreline protection strategies employed today. In 1985, out of about 400 miles of eroding upland shorelines along the Bay main stem and major tributaries, about 58 miles of shoreline were defended by bulkheads or revetments and about 18 miles had groins and groin fields alone. By 1990, defended shorelines had increased 13 miles (22%) to cover 71 miles of eroding upland shorelines. The increase in the use of groins has amounted to about 70%, for a total of 26 miles by 1990 (Hardaway et al. 1992).

A. Bulkheads and Seawalls

In an effort to protect shoreline properties, wood bulkheads and concrete "seawalls" were actively installed in the 1950's, 1960's and 1970's. These were primarily "defensive" structures, built as a last line of defense to impinging wave action. Some of these structures still remain and are to some degree intact. However, most that were built along the Bay stem and major tributary estuaries have deteriorated, been rebuilt or have been replaced by rock. Wood bulkheads are still extensively employed today, the craftsmanship and wood preservation methods have improved since the late 1970's and a 20 year structural life can be expected.

Bulkhead and seawall are two terms often used to denote the same type of shoreline protection structure. There is however, a significant difference in that bulkheads are generally smaller and less expensive than seawalls. Bulkheads are usually made of wood and are designed to retain upland soils and often provide minimal protection from severe wave action (Figure 5, page 10). Seawalls are often made of poured concrete and are designed to withstand the full force of waves (U.S. Army Corps of Engineers, 1984).

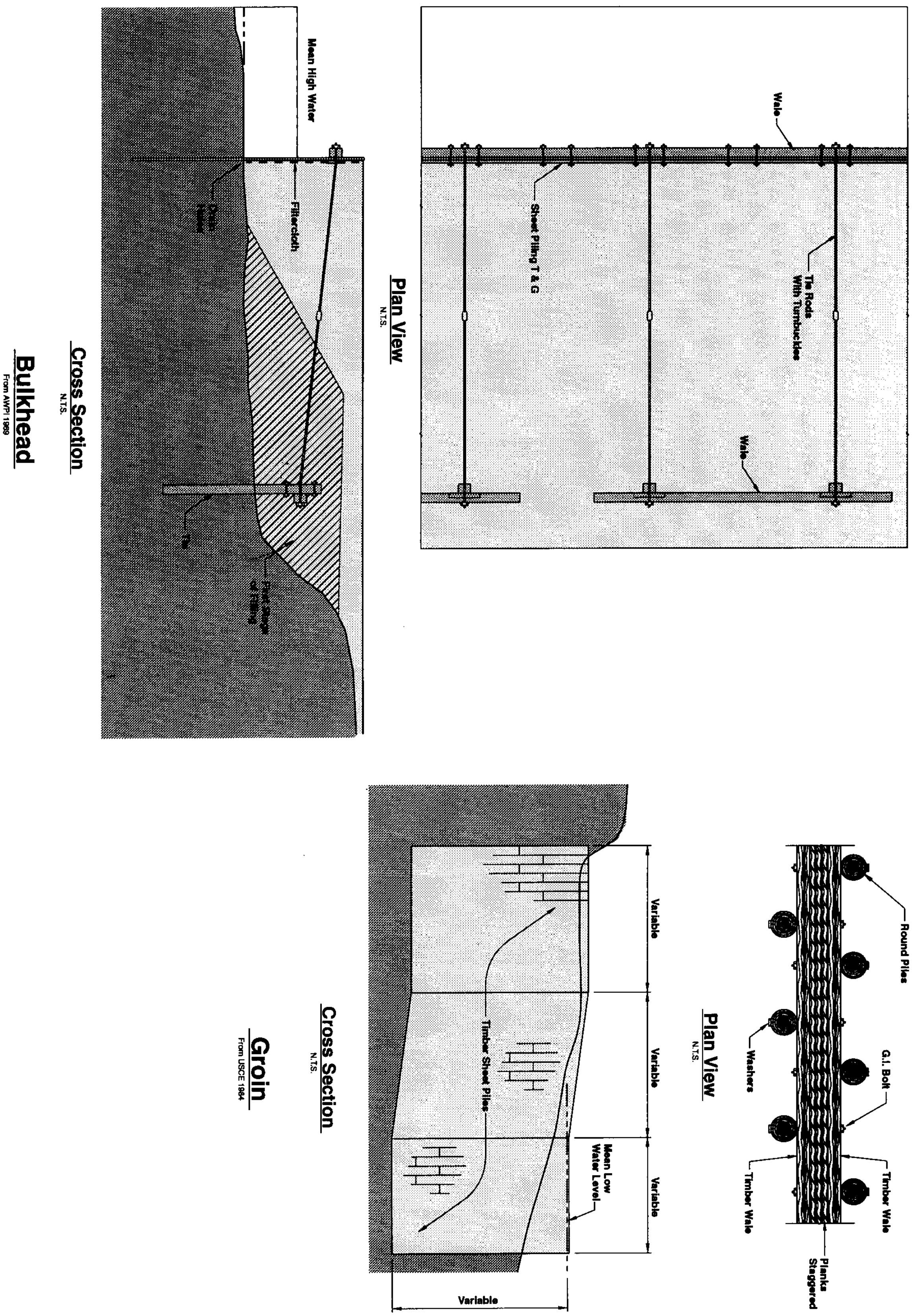

FIGURE 5. Wood bulkhead and groin: typical cross-sections and plan views. (After Reynolds and Hardaway, 1995)

B. Revetments

Rock (rip-rap) revetments became more widely used in the late 1970's, 1980's and 1990's. Today, the structural integrity of a properly designed and constructed rock revetment can be expected to last 50 years or more. The life of the rock will be considerably longer. The sloped and roughed face of the stone revetment decreases wave reflection and nearshore bottom scour. Bottom scour that causes increased depths can threaten the long term integrity of any shoreline protection system if not properly designed and installed.

Figure 6 (page 12) shows a design cross-section for a stone revetment placed along a high bank situation. The height of the structure should anticipate wave runup and overtopping. Bank grading is usually necessary to obtain a stable slope condition. Armor stone must be of good quality and proper size to withstand design wave heights anticipated for any given shore reach. There are other suitable types of armor units made of pre-cast concrete but they are specialized devices and beyond the scope of this report.

Along eroding marsh peat shorelines, low revetments can be installed. They are called marsh toe revetments (MTR) and special attention must be paid to potentially soft peat foundation conditions where unwanted settling might occur. Filter cloth is highly recommended as a structural underlayment to prevent differential settling.

C. Groins

Also profuse during the 1950's to 1980's was the use of groins to entrap sand and build what usually was only a decorative beach area. These structures have been traditionally constructed of wood (Figure 5, page 10). When used with or without a defensive bulkhead or "seawall," groin and groin fields can cause significant impacts to adjacent unprotected shorelines.

On the positive side, if one was a landowner, a relatively wide sand beach might accrete on the updrift side of the groins. If enough sand were available, the shoreline banks would gain some degree of protection. On the negative side, the sand build-up would prevent sand from reaching downdrift shores, decreasing beach widths and increasing the potential for shoreline erosion in these areas.

Spurs have been used with good success to help reduce the downdrift erosive effects of groins. Spurs are shore parallel features placed on the downdrift side of a groin to help prevent flanking (Figures 7A and 7B, pages 13 and 14). They will redirect incoming waves to allow a sheltered area in the lee and promote the accumulation of sand. Groins are still a popular item today and can be at least enhanced with the addition of beach fill. It is, in fact, the beach that offers the protection to adjacent upland banks not the groins themselves.

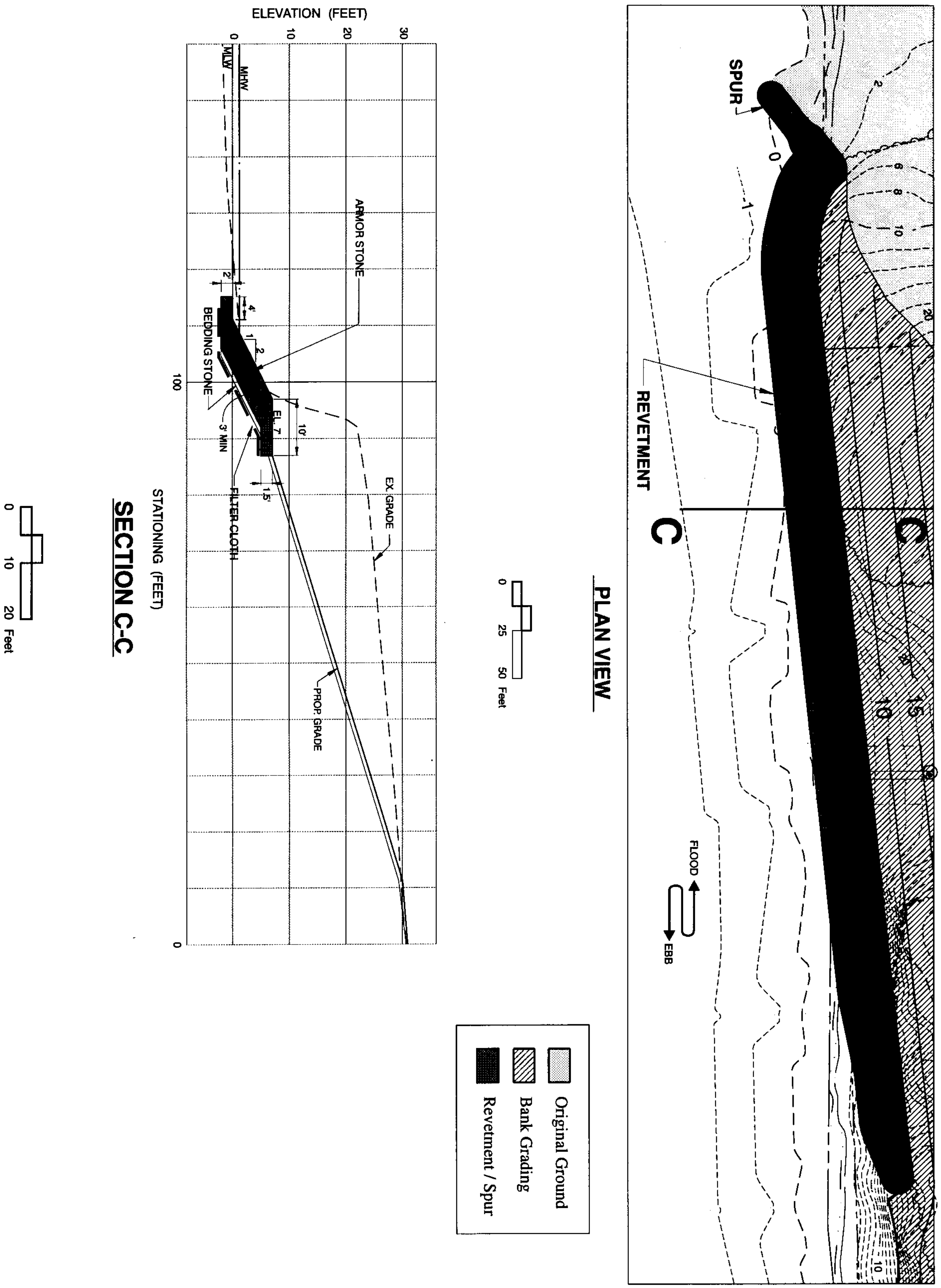

FIGURE 6. Stone revetment: Typical cross-section and plan view. (After Reynolds and Hardaway, 1995)

D. Breakwaters and Sills

The use of offshore breakwaters for shoreline erosion control as well as for maintaining a recreational beach has increased significantly over the past decade . Breakwaters are considered "offensive" in nature because they address the impinging wave climate before it reaches upland properties. Breakwater systems are designed to create stable beach planforms (with beach nourishment) which in turn will allow establishment of various species of marsh grasses at the site (Figure 8, page 15).

Although, subaqueous bottom is covered initially by the breakwater system, intertidal and marsh habitat are ultimately created. The breakwater units themselves take an active part in the wave attenuation process along with the encapsulated pocket beaches. As with groins and other shoreline structures, the use of breakwaters must be designed with the potential impacts to the adjacent shoreline in mind.

Figure 9 (page 16) shows design elements for a typical breakwater system. Primary parameters are breakwater length (LB), distance offshore (XB), the gap between breakwater units (GB) and the maxi-

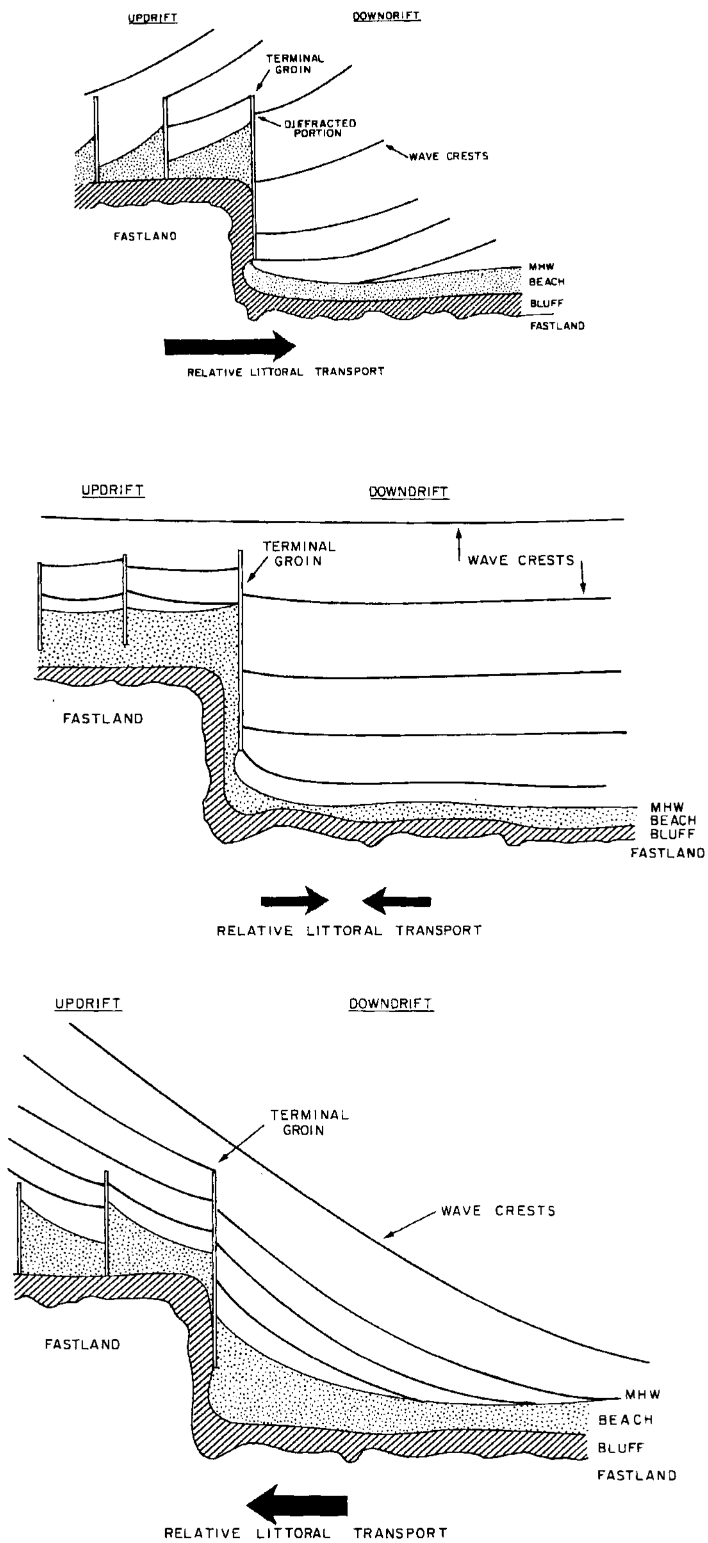

FIGURE 7A. Groin field depicting downdrift offset and different wave approaches. (After Anderson et al. 1983) mum embayment indentation distance (Mb). These parameters revolve around the minimum beach width (Bm) required for the design level of shoreline protection. Hardaway et al. (1991), found the optimum ratio for a stable bay shore planform is a Mb:GB of 1:1.65.

Sills are a cross between rock revetments and offshore breakwaters. Rock sills generally have a "free standing" trapezoidal cross-section similar to breakwaters but are smaller in dimensions, built relatively close to shore and are usually continuous (Figure 10, page 17). In general, beach fill is needed to bring the backshore up so as to establish a marsh fringe in the lee of the sill. Sills can be used in higher wave energy regimes to establish intertidal marsh grasses. Once again, potential impacts to adjacent shorelines must be considered.

E. Beach Nourishment

Beach nourishment used as the sole method for shoreline erosion control is generally limited to reaches designated for dredge material disposal or public beaches. This is usually adjacent to navigation channels that require maintenance dredging or public beaches. Beach nourishment for shoreline erosion control

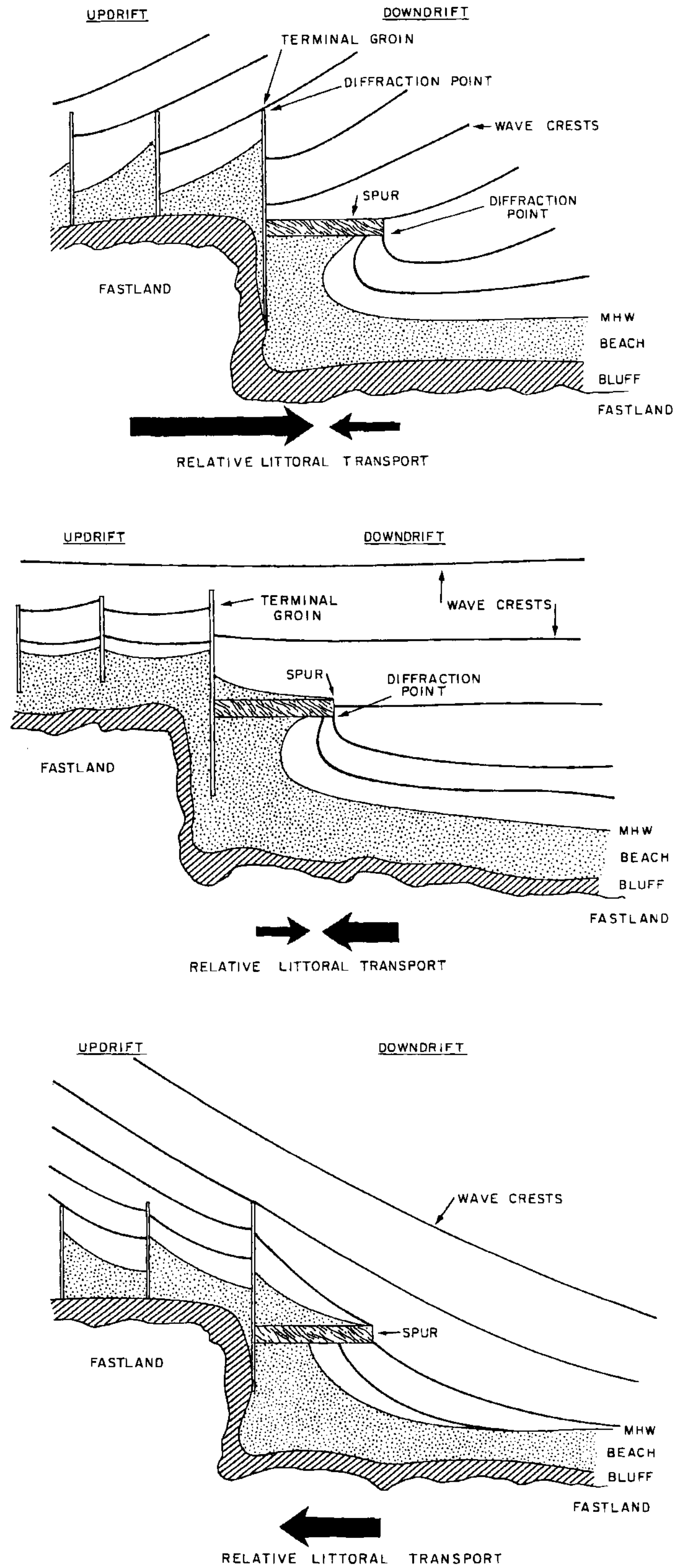

FIGURE 7B. Groin field with spur addition on downdrift side of "terminal" groin. (After Anderson et al. 1983)

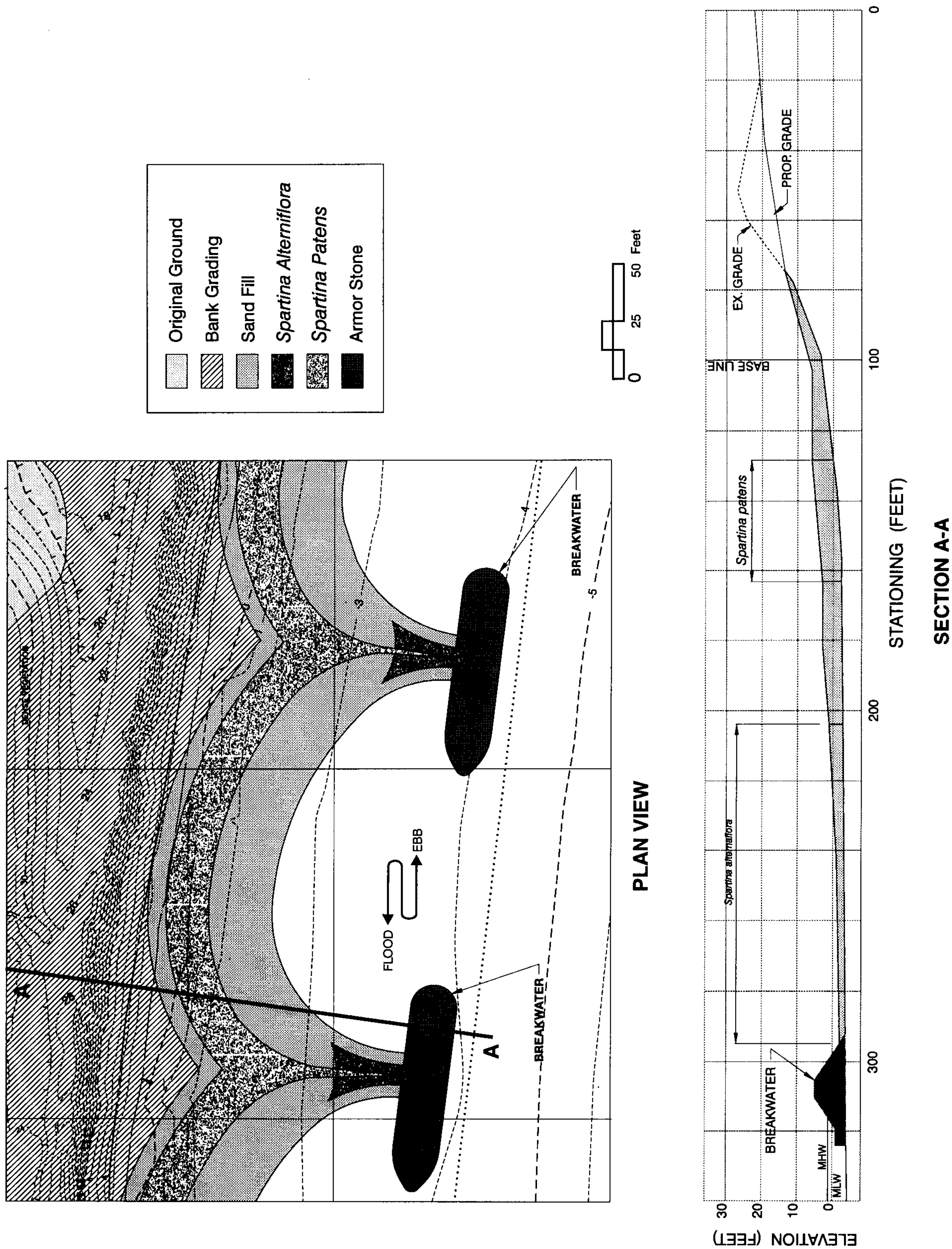

FIGURE 8. Breakwater: Typical cross-section and plan view. (After (Reynolds and Hardaway, 1995)

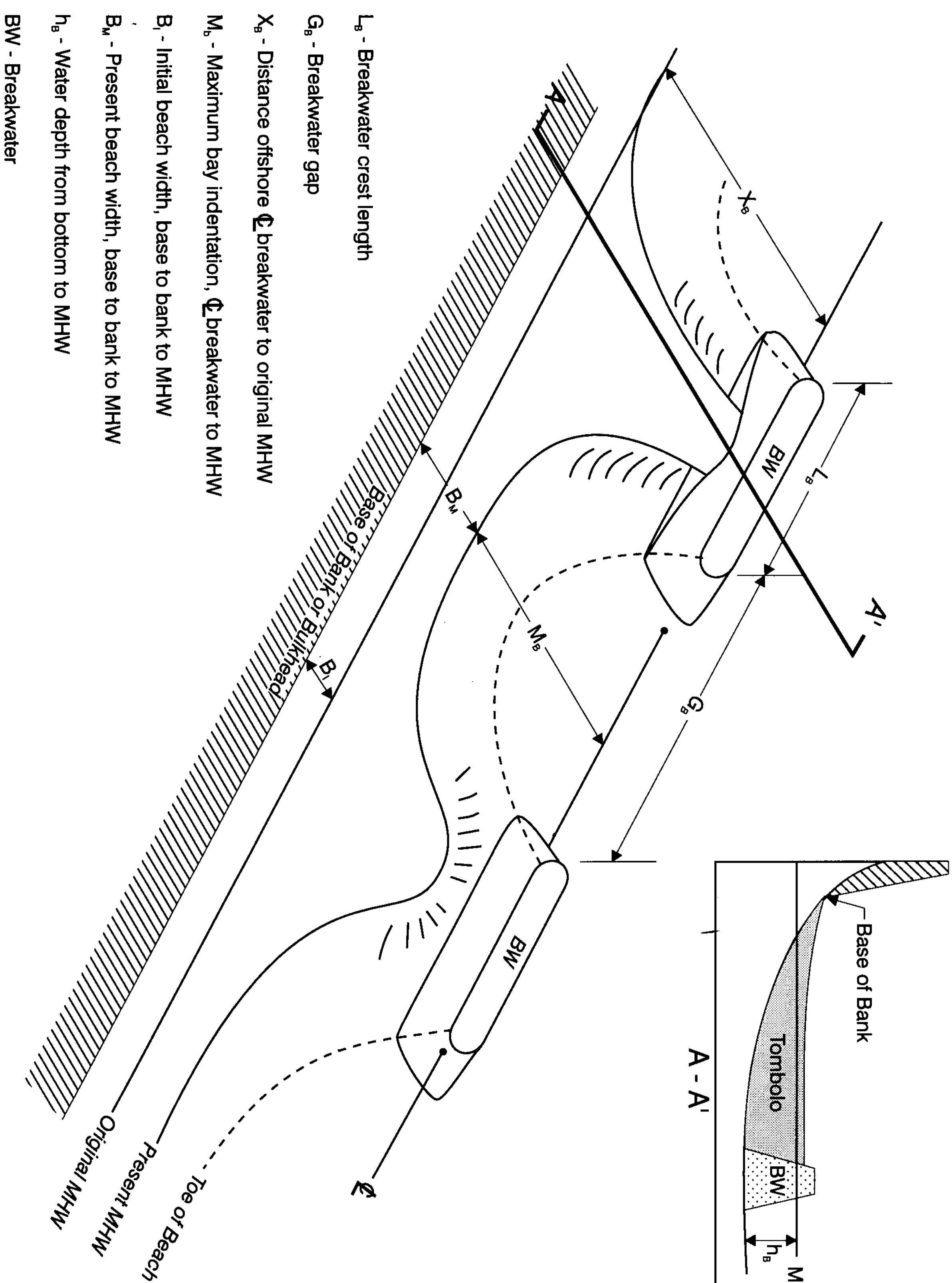

FIGURE 9. Breakwater design parameters. (After Suh, 1987)

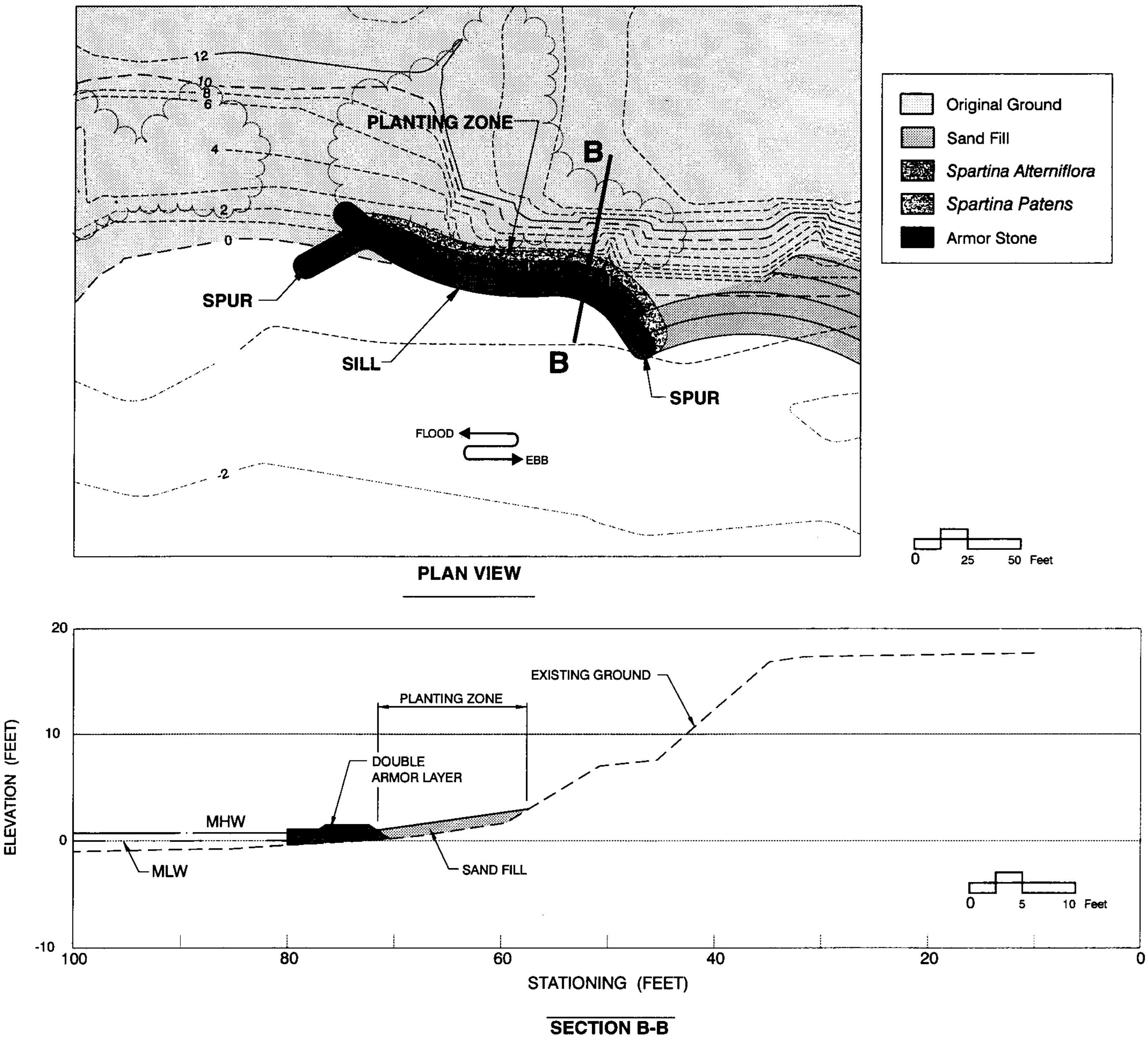

FIGURE 10. Sill: Typical cross-section and plan view. (After Reynolds and Hardaway, 1995)

on properties remote from those circumstances is usually performed in conjunction with structural applications such as groin fields or breakwater systems.

F. Marsh Fringe

The use of planted marshes to create a protective fringe is usually restricted to very low energy shores of tidal creeks with fetch exposures of less than 1/2 mile. In some cases the marsh can be reestablished on the existing substrate, in others a wider marsh substrate can be made using sand fill (Figure 11). Marshes planted behind breakwaters and sills allow fringe establishment to be extended to higher wave energy shorelines. This method is recommended as long as it is part of a long term shoreline management scenario.

G. Headland Control

Addressing shoreline erosion and developing shoreline management scenarios is most effectively accomplished on a reach basis. Headland control is a concept that can allow long stretches of shoreline to be addressed in a more cost/effective fashion. This is accomplished by accentuating existing features or creating permanent headlands that allow adjacent, relatively wide, embayments to become stable planforms (Figure 12). This can greatly reduce the cost of managing the shoreline reach by reducing the linear feet of structure necessary. Although a somewhat new concept around the Chesapeake Bay region, it is a well established methodology elsewhere around the globe. The main problem is coordination of funds and resources for shoreline reaches with multiple waterfront ownership.

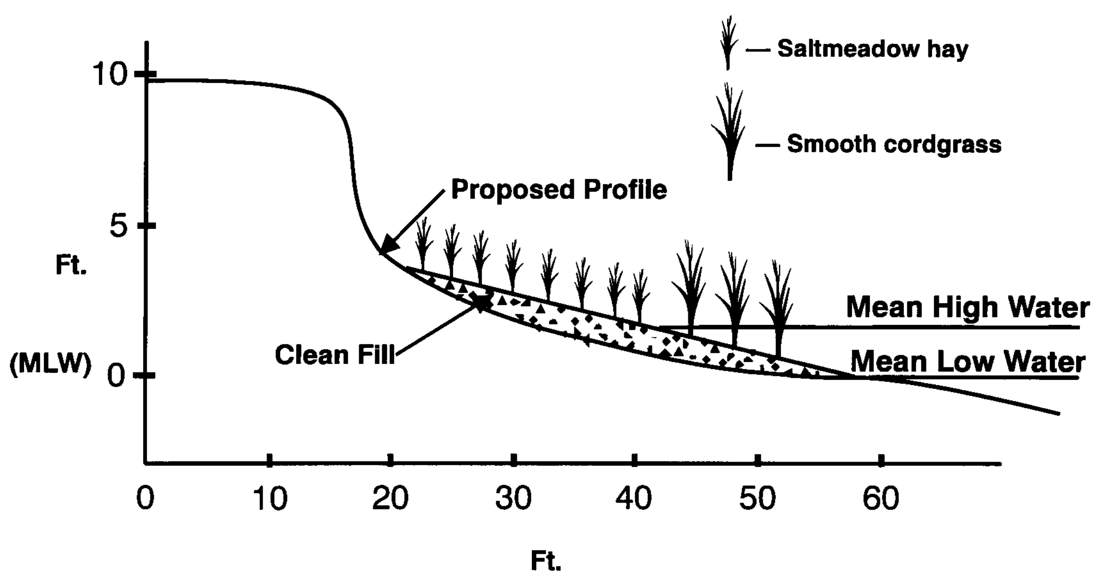

FIGURE 11. Marsh fringe establishment using sand fill for creating a growing substrate. (After Barnard and Hardaway, 1994).

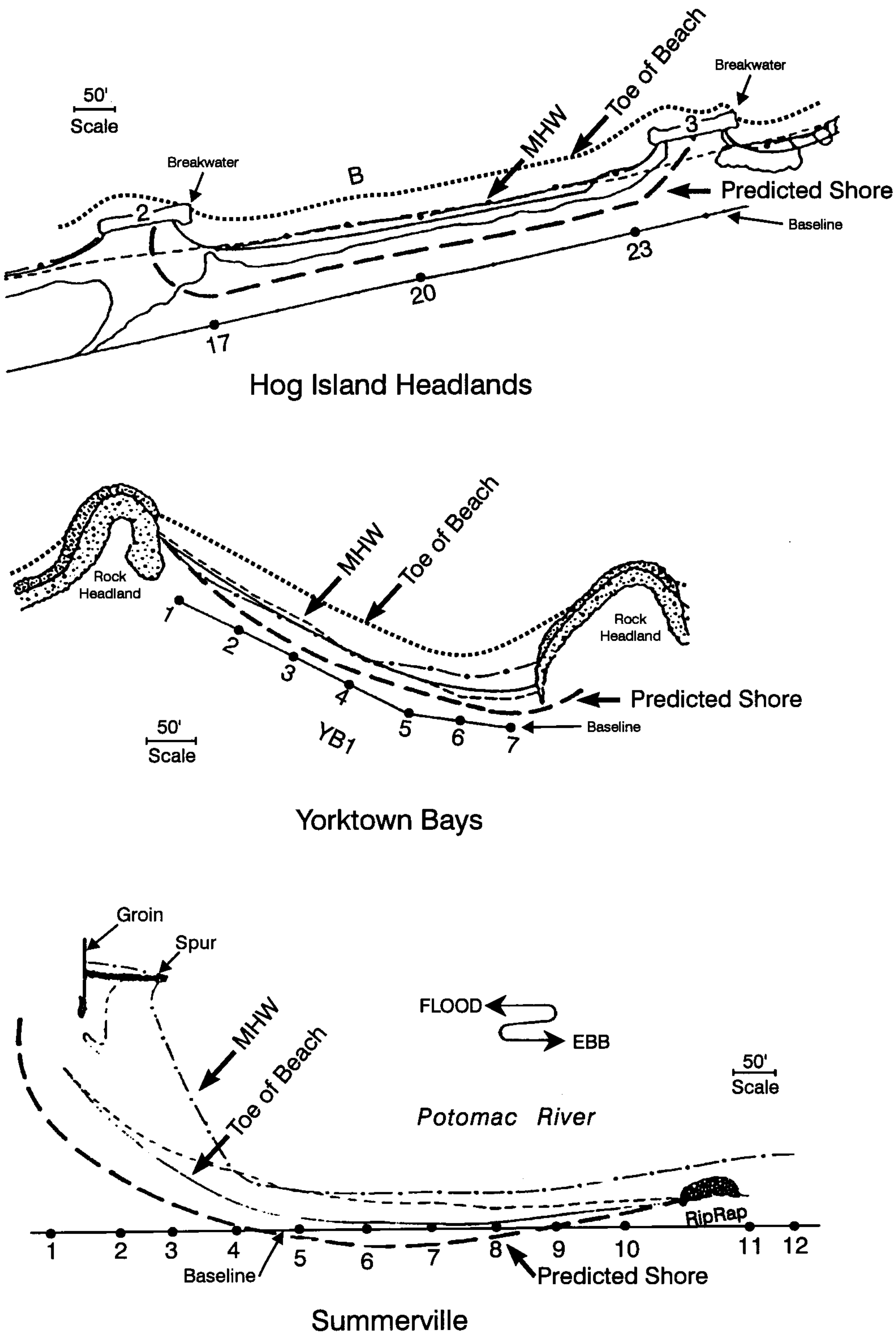

FIGURE 12. Headland control at Hog Island Headland (James River, Surry County), Yorktown Bays (York River, Yorktown), and Summerille/Staples Property (Potomac River, Northumberland County).

H. Other Elements

There are many situations where existing structures must be accounted for in designing and installing a new shoreline protection system. Adjacent structures must be incorporated in a common sense fashion especially if it differs significantly from the proposed strategy.

The use of broken concrete, a very common restoration by-product, in place of rock for shoreline protection systems can be done as long as the material is free of re-bar and conforms in dimensions to a comparable rock structure. The key is proper interlocking of concrete pieces. Long and flat slabs are cumbersome and should be broken up to produce more equidimensional sections. Broken concrete might best be used as an underlayment upon which rock armor can be placed in revetments, breakwaters and sills.

The use of poured or placed concrete seawalls is beyond the scope of this report. Concrete seawall construction is very site specific and should be designed by a qualified shoreline professional.

There are other erosion control methods in limited use around the shorelines of Chesapeake Bay which utilize other construction materials such as concrete forms, gabions and plastic bags. These methods are used by landowners who desire an initially cheaper treatment method. However, design elements must still be adhered to and long term maintenance should be expected. What we have portrayed are the more common, reasonably sound methods used for shoreline protection with a discernible track record. The preference for stone over wood is a simple fact of the long term durability of stone if properly designed and installed. However, many applications are more practically treated with traditional bulkhead, especially in fetch limited situations.

VI. Application of Shoreline Strategies

A. Introduction

When shore zone features that dictate upland bank stability (i.e. beach, fringe marsh, etc.) become too narrow to protect the upland region, erosion is the result. Shoreline erosion control is simply providing a man-made shore zone feature to protect the upland. The level of protection will in large part be determined by the size and placement of the shore protection system for a given storm scenario.

There are three basic approaches when designing a shoreline protection system:

1. **Defend** an eroding bank with a defensive structure such as bulkhead, seawall or revetment.
2. **Maintain** and/or enhance an existing shore zone feature such as a marsh fringe or beach that is presently offering a limited amount of protection. This can be accomplished by a marsh toe revetment, sill or breakwater system.

3. **Create** a shore zone system of beaches and marsh fringe. This is best done with a breakwater system or sill. Beach nourishment is usually necessary to provide the proper template for a beach and marsh substrate.

The dimensions of any shore protection system are dependent on wave climate, costs, what is being protected and what level of protection is desired (i.e. for a design storm surge and wave height).

B. Low Wave Energy

In the low wave energy environments (e.g. small tidal creeks), shore types are usually slowly eroding upland sediment banks or marshes. Shorelines with a sufficiently wide marsh fringe generally have little or no problem with upland bank erosion because established marsh fringes will absorb most of the low wave energy before it can reach the upland banks.

Shorelines that have exposed and eroding upland banks most likely had a marsh fringe in the past. However, the marsh has slowly eroded away leaving the base of the upland vulnerable to wave attack. Often times on low energy shorelines, the base of bank (BOB) is eroding and the upper bank face is relatively stable as evidenced by vegetation. In these cases the bank does not require grading and only the base need be protected.

In many instances overhanging tree limbs shade out the marsh fringe leaving the base of the upland banks vulnerable to even the slightest wave action. It is also in the low energy regime that boat wakes may present a problem and be a dominant factor in shoreline erosion.

Recommended erosion control measures in the low energy wave regime include marsh planting and bank grading, marsh toe revetments, small stone breakwaters or sills (to maintain beach fill) and small stone revetments or bulkheads. Something as simple as pruning overhanging tree limbs to allow better sunlight may be the answer where a sparsely vegetated fringe already exists.

The use and enhancement of vegetation both on the upland and the shoreline are highly recommended, because vegetation filters sediment and nutrient-laden storm runoff and offers an erosion resistant turf (Barnard and Hardaway, 1994). Established marsh fringes also denitrify nutrient laden water from groundwater seeps and springs. With fetch exposures of less than 1/2 nm, marsh fringe establishment is a very viable option. If there is an existing narrow marsh, then it can be enhanced with a additional plantings or a low sill.

A marsh toe revetment (MTR) is used to protect an eroding marsh fringe that is presently protecting the upland. A rock toe wedge placed against the peat scarp over filter cloth may be sufficient in lower wave energy areas. As fetch exposures increase toward 1 nm, the use of a splash apron (3 to 5 ft wide) as a landward extension across the top of the marsh scarp is recommended. The splash apron will help prevent scouring of the marsh peat behind the MTR which can cause landward migration of the rock and reduce the height of the structure, adversely impacting its effectiveness. Rocks should be at least Class I rip-rap (50 to 150 lbs.) (Virginia Department of Highways and Transportation, 1982) (VDOT).

A sill may be most effective in a situation where the existing marsh is inadequate or no marsh or little beach exists and the BOB is eroding. A sill is generally placed at or near MLW over filter cloth with some sand fill in the lee to provide a substrate for marsh establishment. The height of the sill should be at least equal to mean high water (MHW) for adequate backshore support. Again VDOT Class I rip-rap is usually sufficient.

A revetment can be used against an eroding upland bank. In the low energy regime the height of the structure will be determined by the design water level and whether the bank needs grading. Since wave heights of less than 1 ft should be expected, the armor stone can be relatively small (i.e. Class I). Also, the relatively low wave energy means that the structure elevation need only be for the design storm surge. For instance, if one is designing against a 50 yr storm surge with a high bank, the storm surge in the lower Bay area is about 6.0 ft MLW. The height of the revetment need only be about 6.0 ft MLW with a small splash apron of 3 to 4 ft. Filter cloth is recommended as an underlayment and dense vegetation should be established at the rock/upland interface.

Wood bulkheads are very popular along the tidal creeks of the Commonwealth because they allow lawns to extend essentially to the waters' edge. The "Rule of Thumb" for bulkheads is to have at least the same length of structure in the bottom as above. For 8 ft sheeting the structure should have at least 4 ft penetration below MLW. For this scenario the top of the structure would be +4 ft MLW and would be overtopped about once a year in the lower Bay region.

Groins can also be used along low energy shores. They have been successfully used in conjunction with beach fill and marsh emplantations around the bay. They can be stone or wood and are generally low profile in design. Groins may not be appropriate in areas of little or no sand supply and if utilized, accompanying beach fill is recommended.

One key element to be considered is the foundation conditions which are determined by the substrate. Soft clays and peats need to be properly accounted for with added filter layers or excavation to prevent settlement of the structure. This is particularly important with rock gravity structures like revetments, breakwaters and sills. Also, in some areas a hard marl substrate may prevent sheetpile penetration for wood bulkheads and a gravity rock structure may be more suitable.

C. Medium Energy

Medium energy wave environments are generally located along main tributaries of the Chesapeake Bay. Shoreline types typically include moderately to highly eroding upland banks and marsh shorelines. The existing shore zone features must be wider in this environment to accommodate increased wave energy in order to have a stable upland bank.

Recommended abatement measures in the medium wave energy regime include bank grading when using bulkheads, stone revetments and headland breakwaters emploring beach fill and marsh planting. Along eroding marsh shorelines the use of marsh toe revetments and sills are recommended.

Marsh fringes cannot be adequately established along shorelines with fetch exposures of greater than about 1/2 nm. However, marsh grass growth can be established in conjunction with breakwaters and sills and should be used to create an erosion resistant turf in the lee (landward) of these systems.

Marsh toe revetments should have a splash apron when used along medium energy shorelines. It is also important to make sure the structure ends either by a return into the marsh or by designing the last 25 ft or so of structure as a free standing sill. Without these features, flanking of a MTR is likely to result in failure at the ends of the structure. Armor rock size should be minimum VDOT Class II rip-rap which ranges between 150 and 500 lbs and the use of filter cloth is recommended.

A rock sill over filter cloth can be used to enhance an existing eroding marsh by placing it far enough offshore to widen the marsh to a protective width. In the case of medium energy shorelines a marsh fringe of at between 40 to 70 ft may be needed to attenuate wave action during seasonal storm events. During more extreme events with water levels exceeding 3 ft MHW (about every 10 yrs in the lower Bay) some wave action may penetrate this system. Therefore, the sill height should be at least 1 foot above MHW.

A breakwater system can be used cost effectively along medium energy shoreline. The "weak link" in the system is the mid-bay backshore region of the beach fill shore planform. The beach width in that area should be at least 35 ft wide from MHW. Armor rock for breakwaters in the medium energy regime should be VDOT Class III rip-rap (500 to 1500 lbs). Larger rock are necessary on breakwater structures because being situated offshore, they receive a relatively higher impinging wave than shorebound structures like bulkheads and revetments. Once again the use of filter cloth as an underlayment is recommended.

One important consideration in the use of breakwaters for erosion control is the potential impacts to adjacent shorelines. Short breakwater units placed closer to shore can help abate downdrift effects when used as an interface between the main breakwater system and the adjacent unprotected shore (Hardaway et al. 1993). Also, the core elevation of the breakwater should be designed for the desired sand attachment (tombolo) elevation.

Breakwaters are not for every landowner and siting should be an important consideration. Breakwater length, gap and distance offshore will be dictated by the shore setting. Usually these systems are best utilized when there is 200 or more feet of shoreline to be treated. Individual breakwater units should have crest lengths of 50 to 70 ft and crest heights ranging from 2 to 4 ft above MHW.

Revetments installed along medium energy shorelines should have at least VDOT Class II in their two armor layers. Shoreline projects that occur on the higher range of fetch exposures, especially on the lower portions of the main tributary estuaries, should consider VDOT Class III armor or larger. Revetment height and scour depth are important considerations as well. Depending on bottom conditions scour depths of up to 3 ft should be considered possible for the toe of the structure. The top of a revetment should be at least as high as the design storm surge with a splash apron of at least 4 ft. The entire structure should be underlain with filter cloth for the bedding layer to sit on.

The use of bulkheads versus stone revetments on medium energy shorelines should be carefully considered in terms of cost and performance. The "Rule of Thumb" of at least 1/2 down and 1/2 up still holds true. However, the potential for scour and increased bottom depth with time is the greatest with a vertical structure. Therefore, depth below existing MLW should be the line of penetration not the existing beach or backshore.

Along medium energy shorelines low profile groins are generally ineffective for long term shoreline protection. Longer, higher groins are considered unacceptable because of potential sand damming and downdrift impacts. If emplaced, groins and groin fields should include beach fill and at least a spur on the downdrift structure.

D. High Energy

High energy wave environments are generally located on the main stem of the Chesapeake Bay. Shoreline types include highly eroding upland banks, sand beaches and marsh shorelines. The increased fetch in these areas results in larger waves impacting the shoreline under storm conditions. This increase in the size of waves results in a concomitant increase in the cost for a properly designed structure. Protective measures such as bank grading, marsh establishment, and beach fill may be used in these areas, but only in combination with headland breakwaters, sills and groins. Stone revetments, seawalls and bulkheads require more runup and overtopping considerations than similar structures along medium energy shores.

Marsh toe revetments can be used but with the increased rock size requirements, a sill structure should be considered. Armor rock should be VDOT Class III for sills along high energy shorelines. Increased armor size increases the thickness of the structure to accommodate two layers of armor stone. Again, filter cloth is recommended.

Breakwater systems along high energy shorelines are best utilized when there is at least 300 feet of shoreline to be considered. Beach fill is usually necessary to provide the proper design beach planform. The mid-bay beach width should be at least 50 ft from MHW to BOB with an elevation of 3 to 4 ft MHW at the backshore BOB interface. Armor stone should be minimum VDOT Class III but a better range is 2000 to 4000 lbs to provide long term stability. On extreme exposures, such as along Willoughby Spit, armor should be even larger. Individual breakwater units should have crest lengths of 70 ft to 200 ft and crest elevations of 3 to 5 ft MHW depending on project goals.

Once again, interfacing a breakwater system into adjacent shorelines is critical for long term continuum of reach control of shoreline erosion. That is why long stretches of shoreline are best treated and ended at a convenient reach break such as an existing shoreline structure, inlet jetty or a natural headland. Planting the backshore and tombolo area of a breakwater system is necessary to create an erosion resistant turf. A low dune can also be established to provide sand storage for an extreme storm event.

Revetments built along high energy shores need to be properly sized to withstand expected storm surge and accompanying wave conditions. Armor stone should be at least VDOT Class III but larger ranges are recommended. Depending on site conditions, scour depths of up to 4 ft should be accounted for either by toe excavation or a wide toe apron of at least 6 ft. Splash aprons should also be a least 6 ft. wide. The larger size of armor rock should be placed at the toe of the structure for support.

Return sections for revetments should be built well into adjacent banks and could even be free-standing (trapezoidal in cross-section like a breakwater) as shoreline erosion will proceed on adjacent unprotected shorelines. Severe flanking will cause a structural failure of a revetment wall but not a free-standing design. Once again treating longer reaches of shoreline is a more cost effective means of erosion control.

Bulkheads built along open high energy shorelines should be fairly massive in dimensions. Potential scour problems can be treated with the addition of short groins. Some sand may be trapped by the groins which will help reduce storm induced scour. Adequate return walls must be included so backfill is not lost leading to total structural failure.

Groin fields have been effectively used along high energy shorelines because there is often more sand available to the littoral system due to high historic rates of erosion. Downdrift impacts can be minimized with the use of spurs. It should be emphasized that during storm conditions, it is the encapsulated beach that is the wave attenuating element and not the groin itself. Long term beach maintenance, in the form of nourishment, should be anticipated as adjacent shorelines are structurally treated and sand sources reduced within a given reach.

E. Other Comments

Headland control can be applied to all wave energy regimes but is more appropriate along medium and high energy shorelines where cost can become a factor. Eroding agricultural and unmanaged wooded shorelines are excellent applications for headland control. Establishing or enhancing headlands at strategic locations and allowing adjacent shoreline to erode to an ultimate stable planform is a viable, cost effective erosion management option. The addition of beach sands to a shore reach will enhance the headland control method and help create a stable shore configuration.

Beach nourishment as a sole method for erosion is not discussed in detail here because it usually falls to localities to maintain a public beach. However, where there is a need near a navigation channel, suitable dredge material is a very viable means of creating a protective beach and dune system. If dredging is done somewhat frequently, then the dredge material may be all that is needed. Dredged material placement in conjunction with breakwaters or groins can make a good situation better by increasing residence time of the sand along a reach of shore.

VII. Summary

These management strategies are intended to address the goals of both private and public shoreline property owners in Chesapeake Bay and to significantly reduce shoreline erosion in a cost-effective and environmentally acceptable manner. It must also be kept in mind that these are general guides and that a site specific analysis is necessary in each case. Wetlands Boards are urged to evaluate the long term and cumulative impacts of shore protection on a reach basis and if possible, monitor to some degree, the effectiveness of previous installations within a reach.

VIII. Other Sources of Information

There are several publications that deal with shoreline erosion control in Chesapeake Bay. The following is a list of available literature and the agency to contact:

Shoreline Development BMP's: Best Management Practices for Shoreline Development Activities which Encroach In, On, or Over Virginia's Tidal Wetlands, Coastal Primary Sand Dunes and Beaches and Submerged Lands. Produced by the Virginia Marine Resources Commission, 2600 Washington Ave., Newport News, Virginia.

Shore Erosion Control: A Guide for Waterfront Property Owners in the Chesapeake Bay Area. Contact: The District Engineer, U.S. Army Corps of Engineers, P.O. Box 1715, Baltimore, Maryland 21203.

Gloucester County: Shoreline Erosion Control Guidelines. Produced by the Virginia Department of Conservation and Recreation, Division of Soil and Water Conservation, Richmond VA.

Shoreline Erosion in Virginia, C.S. Hardaway and G.L. Anderson, Sea Grant Program, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, VA.

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