Control of Upland Bank Erosion Through Tidal Marsh Construction on Restored Shores: Application in the Maryland Portion of Chesapeake Bay

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ABSTRACT / During the period of 1972 through 1993, Environmental Concern Inc. (EC) and its recent (1989) affiliate Environmental Construction Company (ECC) have completed 216 marsh construction projects to control upland bank erosion in tributaries of the Maryland portion of Chesapeake Bay. Of these projects, 26 have involved marsh construction on unaltered existing shores and 190 have utilized marsh construction on shores that have been restored to former increased elevations through shoreline filling and grading. This paper describes the latter restoration technique. Throughout the 21-year period of applying the technique for long-term upland bank erosion control, refinements to the design standards and criteria for site suitability have been made so as to optimize its successful application. As a result of this experience, a reliable bioengineering restoration technique has evolved to control upland bank erosion. This paper describes the details of this successful technique through a reivew of: (1) its objectives and benefits, (2) suitability of sites for its application, (3) the design of its shore restoration, (4) its construction, (5) its maintenance, and (6) comparison of its cost with those of structural techniques for bank erosion control. Although the technique has only been applied in the Maryland portions of Chesapeake Bay, its applicability should, with modifications, be broadly applicable to all water bodies.

Many studies have been reported regarding the construction of tidal marsh on existing shores for shore stabilization and shoreline bank erosion control (Dodd and Webb 1975, Garbisch and others 1975a, 1975b, Hardaway and others 1985, Knutson 1977, Knutson and Woodhouse 1983, Webb and Dodd 1976, Woodhouse and others 1974, 1976). Whereas the stabilization of existing shores through marsh construction can abate upland bank erosion, this technique can control such erosion only when there is a continuing supply of sand for entrapment by the marsh to build up the elevation of the shore (see Cause of Upland Bank Erosion below).

Little has been published regarding the construction of tidal marsh on physically restored shores for upland bank erosion control. In a report of work completed in 1958, Sharp and Vaden (1970) evaluated the effectiveness of bank sloping and vegetative establishment on the new slopes as a technique for upland bank erosion control.

In this work, shoreline banks were graded landward of the bank's toe to produce new shores that were largely above mean high water (MHW) and suitable for the development of high marsh, dune, and upland plant communities. This work, however, did not pursue the physical restoration of existing shores to control upland bank erosion.

The technique described herein is a variation and extension of that of Sharp and Vaden in that it involves the physical restoration of existing shores to former increased elevations by shore filling and grading, followed by the construction of tidal marsh throughout the restored shores for long term shore stabilization. The results of a study, including statistical analyses, of 100 of our bank erosion control projects (Trettel 1989) assisted in the refinement of the site suitability and maintenance requirements to accomplish and sustain effective bank erosion control.

Cause of Upland Bank Erosion along Shores of Waterbodies

Upland bank erosion along shores of waterbodies arises when the frequency of water contact with the bank face is sufficiently frequent to lead to bank undercutting and subsequent collapse of the bank, with the resultant loss of upland. The rate of bank erosion generally increases as: (1) the frequency of contact of

KEY WORDS: Containment structure; Mean high water; Peak bank; Wave climate

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water with the bank face increases and (2) the wave climate becomes more energetic due to fetch increases and/or increases in boat-induced waves.

The two principal factors that contribute to the increased frequency of contact of water with the toe of bank are: (1) erosion (scouring) of the shore, which leads to a reduction of its elevation; and (2) sea level rise and/or land subsidence, which leads to an "effective" rise of water level relative to the land surface.

Effect of Marsh Construction on Existing Shores for Upland Bank Erosion Control

In the absence of any significant transport of sand to the shore for marsh entrapment, construction of tidal marsh on existing shores will approximately maintain the existing upland bank erosional conditions through: (1) the stabilization of the shore and eliminating its erosion (scouring) and (2) the development of a peat bank whose rate of increase in elevation may correspond approximately to the "effective" rate of rise in sea level.

Depending upon the width of constructed marsh, bank erosion rates may be slightly reduced due to the dissipation of wave energies passing through the marsh (Knutson and others 1982). The widths of the vegetated existing or restored shores that are discussed here are too narrow to either: (1) significantly dissipate the wave energies passing through them or (2) to trap sediments that are finer grained than sand (i.e., silts).

The development of a tidal marsh on existing shores is most effective for shoreline bank erosion control when alongshore and/or offshore littoral transport or continued bank erosion supplies sufficient volumes of sand to the marsh to accomplish bank erosion control. In such instances, the marsh vegetation effectively traps the sand, leading to an increase in shore elevation. As the shore elevation increases through sand entrapment, the frequency of contact of tidal water with the bank face decreases and the rate of bank erosion correspondingly decreases. Bank erosion has been controlled when contact of tidal water with the bank face is, for practical purposes, eliminated (Figure 1).

Throughout the tributaries of the Maryland portion of Chesapeake Bay, there often is no supply of sand to its shores. Shore elevations frequently are below MHW and tidal water interacts with the bank face twice daily for varying amounts of time (Figure 2). As discussed earlier, the construction of marsh on such existing shores will not significantly reduce bank erosion rates.

If there is a supply of sand, its source may be lost due to nearby erosion control projects or the supply may be intercepted by newly dredged channels or diverted by various shoreline developments. In such instances, the potential for increases in shore elevation through sand entrapment by constructed tidal marshes is uncertain. When the source and supply of sand is from the eroding bank in question, property owners understandably are reluctant to lose more land before such erosion may be controlled.

Technique of Marsh Construction on Restored Shores

Objectives and Benefits of the Technique

The objectives of the technique are to: (1) physically restore shores to former higher elevations such that tidal water is excluded from the associated upland bank faces for periods of 6–17 years and (2) assure that the restored shore slopes are sufficiently stable to allow the successful construction of a sustained tidal marsh vegetation community.

The benefits that result from a successful application of the technique include: (1) eliminating the loss of upland, (2) improving water quality of the associated waterbody by eliminating sediment input through bank erosion and by the treatment of stormwater runoff pasing through the marsh, (3) providing habitat and food resources for fish and wildlife, (4) providing enhanced aesthetics to the owners of treated property, and (5) providing possible long-term protection against "effective" sea level rise by virtue of the development of a peat bank over time (see next section).

Suitability of Sites for Application of the Technique

The factors that determine site suitability are: (1) a wave climate that is suitable for the technique, (2) adequate light for marsh plant development, and (3) site conditions that can accommodate the design standard for the technique.

With reference to the first factor, many rhizome-propagating emergent wetland plant species form a tightly woven root mat that in time emerges above the original mineral wetland sediments as a peat bank. Examples are *Juncus, Phragmites, Scirpus, Spartina,* and *Typha* species. The productivity of the belowground portions of these species generally is equal to or greater than the aboveground portions (de la Cruz and Hackney 1977, Gallager and Plumley 1979, Good and others 1982, Hackney and de la Crux 1986, Roman and Daiber 1984, Stroud 1976, Valiela and oth-

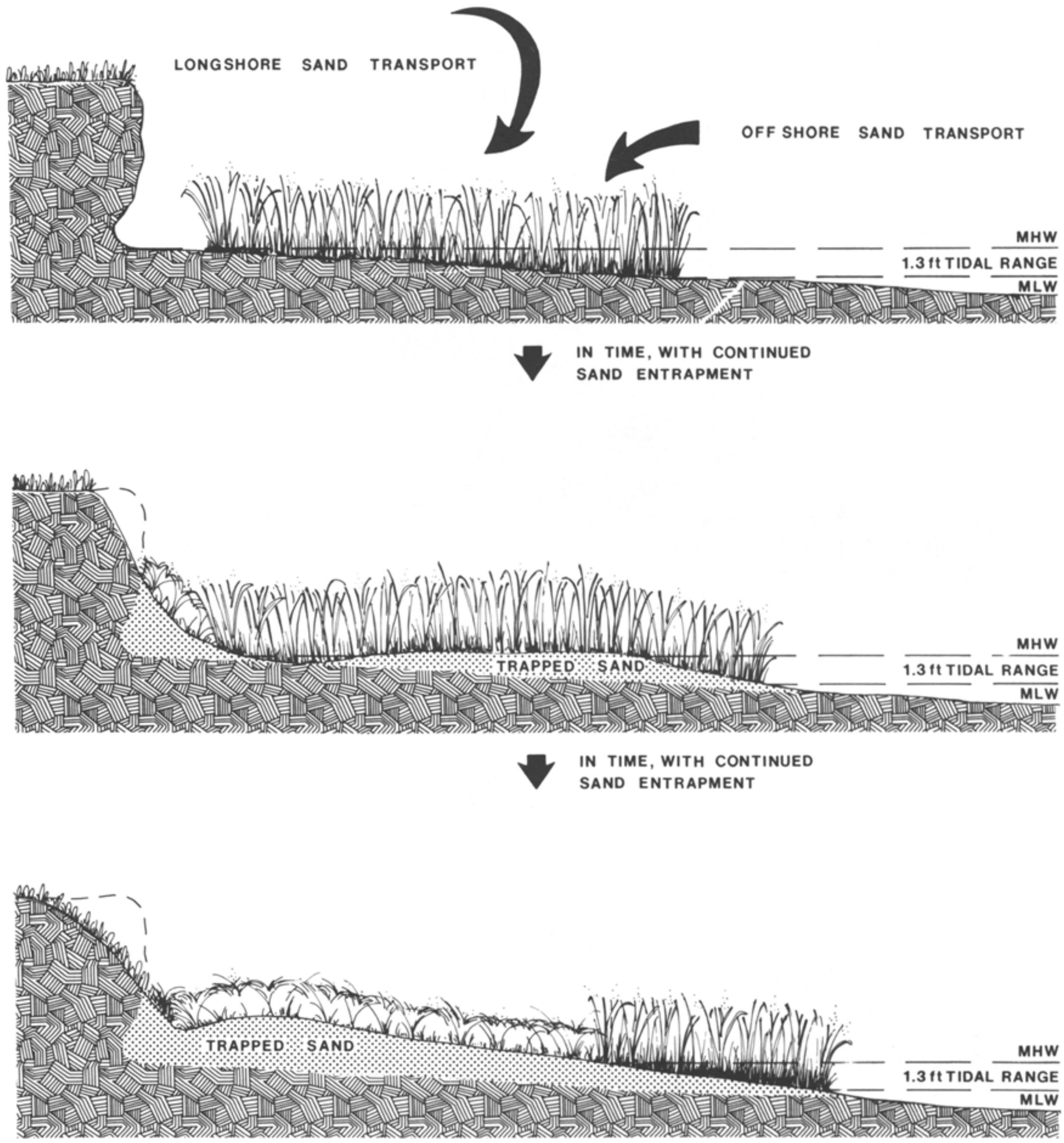

Figure 1. The mechanism of shoreline bank erosion control through marsh construction on existing shores when a supply of sand persists.

ers 1976) and peat banks may rise above the sediment surface in as short a time as three years and be vulnerable towards erosion.

Figure 3 shows a stable 20- to 30-cm (8- to 12-in.) peat bank in an 18-year-old constructed tidal marsh. In Chesapeake Bay, these peat banks have been found to rise above the original sediment surface at a rate that is comparable to the rate of "effective" sea level rise (Garbisch, unpublished). Before the peat bank becomes exposed, tidal marshes growing on stable shores can sustain wave climates generated over extensive fetches of 8–16 km (5–10 mi). However, once the vertical peat bank emerges, its stability dictates the site suitability in terms of fetch.

Considering the: (1) mild wave climate required for long-term marsh peat bank stability, (2) light necessary to sustain normal marsh plant productivity, and (3) site requirements necessary to accommodate the design standard for the technique, a site is suitable for the technique if:

Figure 2. A photograph of a low elevation shoreline in Chesapeake Bay where tidal water interacts with the bank face twice daily.

Figure 3. An 18-year-old *Spartina alterniflora* marsh in San Domingo Creek, Chesapeake Bay, showing an 8–12 in. vertical peat bank.

- there are no open water fetches of greater than 1.6 km (1.0 mi);
- motor boating activities offshore of the site are negligible and are likely to continue to be negligible;
- the shore at the toe of bank (of any height) and channelward receives or can receive through tree removal/pruning and/or bank sloping at least 6 h of direct sunlight daily during the growing season; and
- the slope of the existing shore is no steeper than 10:1 (see Appendix A).

The use of stone breakwaters and/or sills can expand the site suitabilities to greatly more exposed sites. However, in so doing, construction costs can be expected to exceed those of alternative erosion control methods, and the technique will no longer be competitive.

Construction constraints may also limit the site suit-

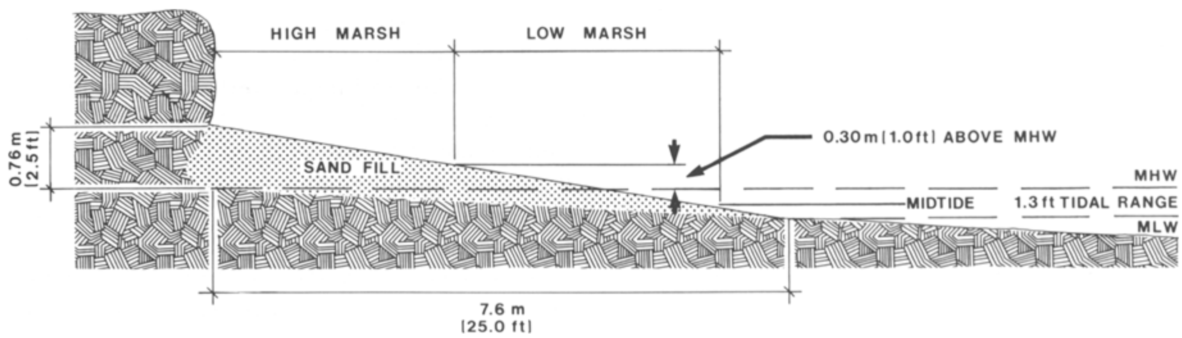

Figure 4. The recommended design standard for the technique when restoring the shore through filling and grading. Tidal range is typical of that for the mid-Chesapeake Bay.

ability. There must be access to the shore for materials and equipment in order to accomplish the work. A contractor who knows what equipment is available for use must determine whether an otherwise suitable site has severe construction constraints.

Design of Shore Restoration Part of the Technique

Design standard. The recommended design standard is to restore the shore using clean sandy materials (see next section) to an elevation that is 0.76 m (2.5 ft) above local mean high water (MHW) at the bank face (or up to the top of the bank when this is less than 0.76 m above MHW) and graded 7.6 m (25 ft) channelward on an approximate 10:1 slope (see Appendix A and Figure 4).

Since, tidal water exceeded +0.76 m (+2.5 ft) MHW ten times over 61 years at Annapolis, Maryland, and three times over 51 years at Solomons Island, Maryland (US Department of Commerce, NOAA 1992), this design standard will prevent tidal water from interacting with the bank face for up to 6–17 years of high tide events in the mid-Chesapeake Bay. The vegetation community, once established, provides additional protection against bank erosion during unusual high tide events.

As an estimate of local MHW, it is recommended to take the average of several lowest elevations on or near the project site that support healthy monotypic stands of *Spartina patens* (saltmarshs hay). In the absence of saltmarsh hay, the average of the lowest elevations where *Iva Frutescens* (marsh elder), *Baccharis hamilifolia* (groundsel bush), and/or *Panicam virgatum* (switchgrass) are growing on or near the project site may be used as an estimate of local MHW (Garbisch 1986, 1989).

Although there may be site-specific justifications to vary the recommended design standard, the authors have found it to:

- provide satisfactory long-term control of upland bank erosion at sites meeting the criteria for site suitability;
- provide an unvegetated restored shore that normally does not adjust (vary) from the design standard by more than 0.15 m (0.5 ft) vertically and 1.5 m (5 ft) horizontally (see Adjustment of Restored Shore below) upon experiencing the site's wave climate; and
- be attractive in cost compared to alternative structural approaches for bank erosion control.

It should be noted that because the restored shore will always have a slope that is greater than the existing shore (see Appendix A), it will be vulnerable to erosion. Vertical and horizontal adjustments of the new shore should be expected following its construction and its interaction with the prevailing wave climate at the site.

It must be emphasized that the design standard is an objective that should not be expected to be realized in all instances. The slope of the restored shore will vary depending upon the slope of the existing shore (see Appendix A) and upon the extent of the shore adjustment (see Adjustment of Restored Shore below) after being subjected to the site's wave climate. This adjustment also will influence the maximum height and length of the restored shore. The extent of this adjustment is determined by both the site's wave climate and the particle size distribution of the sediments used for the shore restoration (see next section).

Shore restoration in Maryland, as described here, requires state and federal wetland permits and possibly county grading and Soil Conservation Service (SCS) sediment and erosion control permits, and Critical Areas approval.

Specifications for sandy fill materials. Suitable fill materials are those consisting largely (>80%) of medium-sized sand with smaller amounts of coarser and finer materials. If sieve analyses are to be performed, >90% should pass a No. 35 standard sieve and <10% should pass a No. 60 Standard sieve. If finer grain sized sandy materials are utilized, possibly greater than acceptable vertical and horizontal adjustments of the restored shore may result after being subject to the prevailing wave climate at the site (see Adjustment of Restored Shore below). If coarser grain sized materials are utilized, salt buildup or desiccation problems due to rapid moisture loss may develop throughout the higher elevations of the shore.

Use of containment structures. Permanent store (riprap) structures are required to contain the sandy shore materials within the limits of construction and within certain sections of the restored shore. By containing the shore sediments, these structures minimize excessive movement of sediments during the critical vegetation establishment period.

Two types of containment structures are used: (1) full containment structures, which are constructed prior to the development of the restored shore; and (2) surface containment structures, which are constructed following the development of the restored shore.

Design standards for the full and surface containment structures are given in Figures 5A and 5B, respectively. Stone having a size range of 30–91 cm (12–36 in.) for the full structures and 30–61 cm (12–24 in.) for the surface structures has been found to be suitable.

If the existing shore sediments are sufficiently soft that the stone might settle and be unstable, a filter fabric should be placed on the shore prior to construction of the containment structures. Suitable filter fabrics for this purpose are MIRAFI-700x and AMICO-1199, or equivalents.

We have found it important that the containment structures have a low profile relative to the restored shore (Figure 5). The higher the structures are placed above the shore surface the greater the wave direction vector with the shore is altered from angular to perpendicular as the waves pass over them. When this happens, scouring of the sediments on the lee side of the structure occurs, leading to shore instability.

The structures are designed so the wave climate is minimally altered while passing over them (Figure 6). We have found empirically that this is effectively achieved when the top of the structure is no greater than 15–23 cm (6–9 in.) above the shore surface.

The positioning of these structures and selection of the structure type will depend upon site-specific conditions. Full containment structures add significantly to construction costs and should be used only at: (1) the limits of construction, (2) sections of shore that approach the limits of tolerable fetch (0.8–1.6 km or 0.5–1.0 mi) for the technique, and (3) points and recesses (coves) of land.

Containment structures should be: (1) placed at about 18 m (60 ft) intervals along linear shoreline sections approaching the limits of tolerable fetch, (2) placed at increased intervals or eliminated as the fetch decreases to negligible, and (3) not be placed at points of discharge of stormwater to the restored shore.

Management of point discharges of stormwater through restored shore. Major points of discharge of stormwater over the bank generally are obvious when inspecting the site. The management of this stormwater can be designed and completed during construction.

Site topographies may have such little relief that minor stormwater discharge points are not obvious. More frequently, however, minor altering of site topography through the operation of heavy equipment along the top of the bank during construction can create slight depressions that become minor stormwater discharge points.

Such minor discharge points may only be discovered after construction and following a storm event. The stormwater discharge erosion gullies in the restored shore then can be managed. If the number of such gullies is large, it may be advisable to regrade the top of bank to convey stormwater to a single discharge point.

Management of stormwater discharge entails the construction of a stone armored swale through the entire width of the shore and about the centerline of the erosion gully. The swale should be 0.3–0.45 m (1–1.5 ft) deep along its centerline and at least five times the width of the erosion gully. The swale should be lined with filter fabric (MIRAFI-700× or AMICO-1199) followed by the placement of 5- to 15-cm (2- to 6-in.) bedding stone on the filter fabric to a depth of about 23 cm (9 in.). The sizing of the swale and the stone will have to be increased for major stormwater discharges.

Construction

Restoration of Shore (filling and grading). After clearing to provide at least 6 h of direct sunlight daily (see earlier section) and after placement of the full containment structures, the correct volumes of sandy materials to achieve the design standard are metered alongshore at the toe of the bank by use of a front-end loader, dump truck, or excavator.

If the bank is not too high or the density of woody vegetation not too great, grading of the fill materials can be accomplished by an excavator. Otherwise, ma-

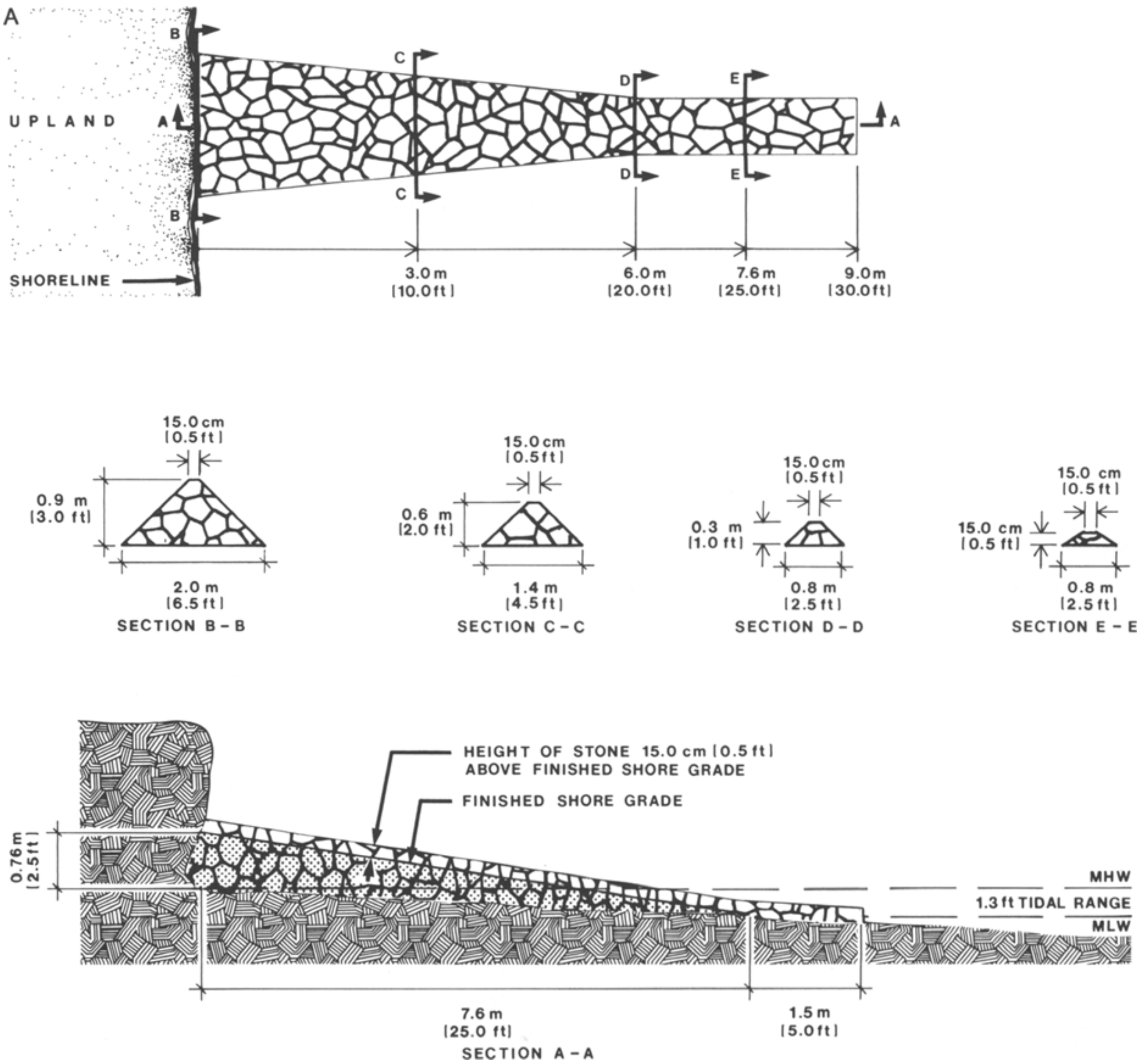

Figure 5. **(A)** The design standard for a full containment structure. **(B)** The design standard for a surface containment structure.

terials are graded hydraulically using tidal water at the site, a high pressure pump, and hose (see Figure 7C). With this grading approach, rough grading is accomplished during times of high tide in order to minimize the loss of sandy materials beyond the limits of fill. Fine grading is completed during times of low tide. The full containment structures can be used to monitor the grade, since the restored shore is at a final grade when its surface is about 15 cm (6 in.) below the top of the structure.

Adjustment of restored shore to site's wave climate. Following the construction of the restored shore and the placement of any specified surface containment structures and stormwater management swales, it is advisable not to do any additional work for a period of two to four weeks. During this period the restored shore: (1) will adjust horizontally and vertically to the prevailing wave climate and become stabilized, (2) may develop minor stormwater erosion gullies that require management prior to planting, and (3) many develop escarpments (lips) during the horizontal and vertical adjustments that require to be hand graded prior to planting.

Planting adjusted restored shore. The optimum time for planting sites exposed to substantial (0.8–1.6 km or 0.5–1.0 mi) winter fetches is during May through

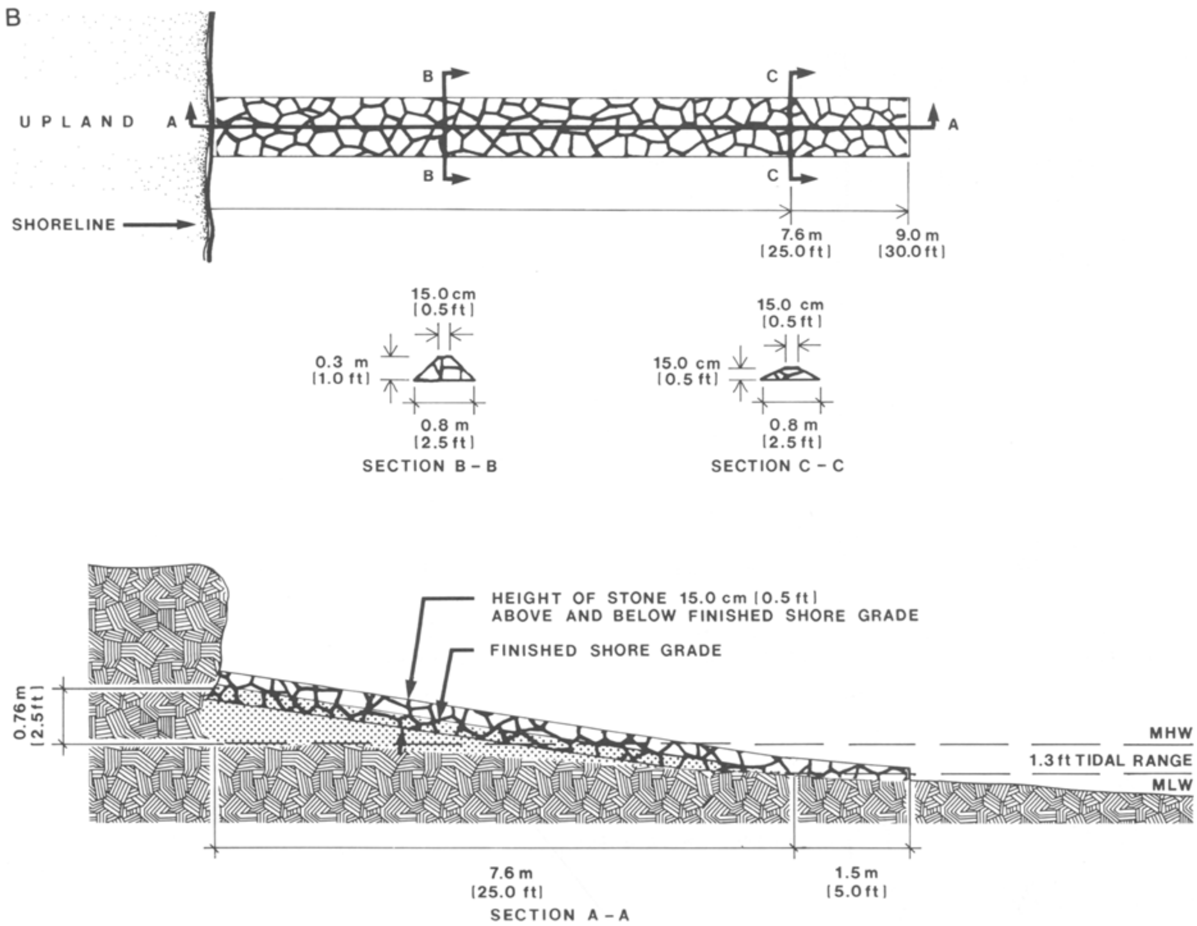

Figure 5. Continued.

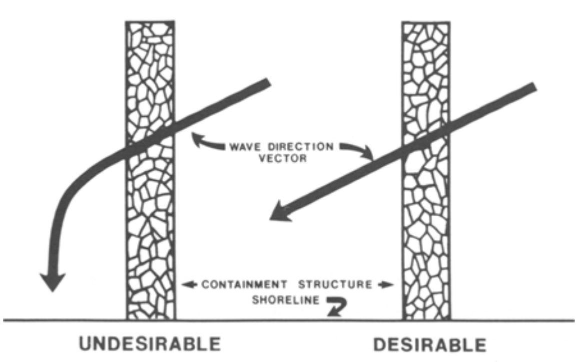

Figure 6. The desirable and undesirable wave climate vectors for waves passing over containment structures.

July. This will allow ample time for vegetation establishment prior to winter stresses. Sites that are extremely protected or exposed only to summer prevailing winds can be planted during any time of year.

Throughout the Maryland portion of Chesapeake Bay, the following prevailing winds exist: spring/summer, S/SW; fall/winter, W/NW/N; storm, NE/E/SE.

The following specifications are provided for planting the restored shore.

For water salinities greater than 3 ppt, plant in staggered rows:

1. *Spartina alterniflora* (cordgrass) 46 cm (18 in.) on center between mid-tide and 30 cm (12 in.) above MHW.
2. *Spartina patens* (saltmarsh hay) 46 cm (18 in.) on center starting one row past cordgrass to toe of bank (top of shore).

For water salinities less than 3 ppt, plant in staggered rows:

1. *Scirpus pungens* (common threesquare) 46 cm (18 in.) on center between mid-tide and 30 cm (12 in.) above MHW.

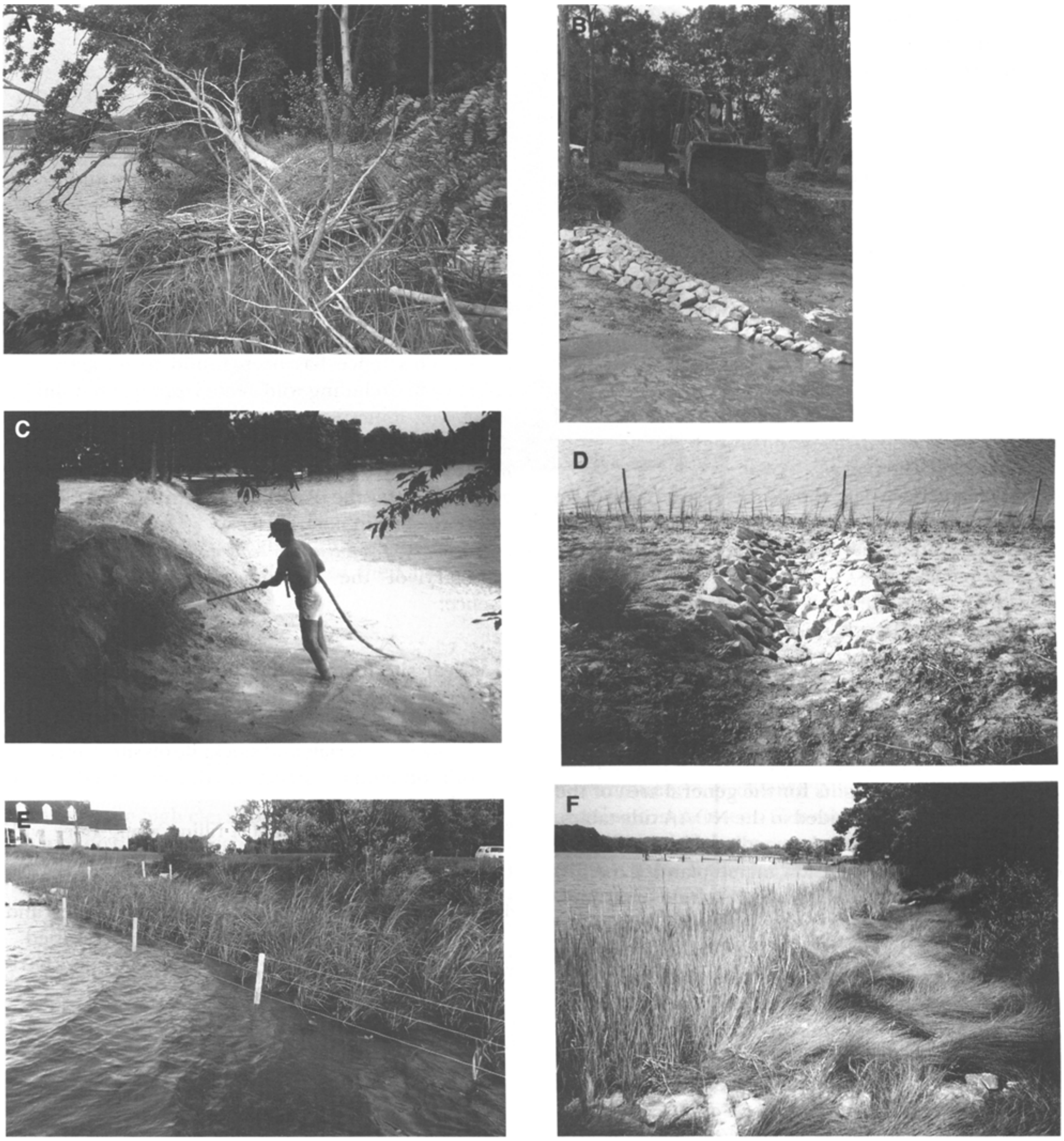

Figure 7. The recommended construction sequence for the technique when restoring the shore through filling and grading. **(A)** A shoreline to be cleared of fallen and leaning trees and of shading trees and limbs of trees. **(B)** Construction of full containment structures and distribute sandy fill materials alongshore. **(C)** Grade the sandy fill materials. **(D)** After waiting two to four weeks, construct stormwater management swales (shown) and surface containment structures (not shown). **(E)** Construct the goose exclosure fence after planting the restored shore. **(F)** Photograph of a typical restored shore four months after planting.

2. *Panicum virgatum* (switchgrass) 30 cm (12 in.) on center starting one row past Common three-square to toe of bank (top of shore).

For all plantings:

1. If planting during the period of May–August, fertilize each transplant in the planting hole with 30 g or 30 ml (1 fluid ounce) of three- to four-month release Osmocote 19-6-12 fertilizer.
2. If planting during any other period, fertilize each transplant in the planting hole with 30 g or 30 ml (1 fluid ounce) of eight- to nine-month release Osmocote 18-6-12 fertilizer.
3. All plant material should be nursery grown in 3.8 cm (1.5 in.) to 4.45 cm (1.75 in.) peat pots and have roots well developed through the sides and bottoms of the pots.
4. All plant materials should be planted 8–10 cm (3–4 in.) below the top of pots in order to minimize washouts due to changes in the grade of the restored shore.
5. If planting in areas where the water salinities are greater than 15 ppt, nurseries should be required to condition the plants to the site's water salinity for one month prior to planting.

In order to identify the planting zones on the restored shore, it is recommended to utilize the daily predictions of tide heights for the general area of the project site that are provided in the NOAA tide tables. Select several days when the predicted high tides are near the high limit for the low marsh planting, i.e., 30 cm (12 in.) above MHW. Go to the site during high tide on one of these days when the weather conditions are not expected to influence the tide, and flag the water level on the restored shore at slack high tide. The low elevation limit of the low marsh planting zone can be identified using an elevation rod or yardstick. Walk down the shore during this same slack high tide and flag or stake the shore when the depth of water equals the difference of 30 cm (12 in.) above MHW and mid-tide for the area (in Figure 4, this depth of water would be 46–48 cm (18–19 in.).

Constructing goose exclosure fence. Plant grazing during the growing season and feeding on the underground rhizomes at other times by Canada geese is highly probable in the Chesapeake Bay region. Several Canada geese can denude a newly planted shore overnight. After a thick root mat develops in two to three years, the task of feeding on belowground plant parts becomes more laborious and protection is no longer warranted. During the interim, it is recommended to construct a goose exclosure fence at the time of planting or before.

Fence construction consists of placing 1.5-m (5-ft) -long 5 × 5-cm (2 × 2-in.) wooden stakes 0.6 m (2 ft) underground over 30 m (10 ft) and 0.6 m (2 ft) channelward of the lowest elevation row of plants and up the sides of the limits of construction to the top of shore (bank face). Three rows of 3-mm (1/8-in.) string spaced 25 cm (10 in.) apart are attached to nails on the stakes staring 25 cm (10 in.) above the shore surface.

If geese frequent the upland areas alongshore and have access to the planted shore, it may be necessary to extend the fence along the top of the shore (top of bank). This fence has been found to be extremely effective in excluding wild geese from planted shores. Tame or domesticated geese, however, may move through the fence to feed on the plants. Periodic maintenance of the fence is a likely requirement, as geese will enter the planted shore through any section where the line in not in place.

Summary of construction sequence. The following is a summary of the recommended construction sequence:

1. Clear site for shoreline light and equipment access. Clear shore of all fallen trees and large items of debris.
2. Bring in materials and stockpile on site. Construct full containment structures during periods of low tide.
3. Restore the shore by: (1) filling alongshore with sandy materials and grading or (2) pursuing alternative designs (see Appendix B).
4. Construct stormwater management swales and surface containment structures where specified.
5. Let the restored shore adjust vertically and horizontally to the prevailing wave climate for a period of two to four weeks.
6. If it has rained during this adjustment period, check the restored shore for the development of stormwater erosion gullies and construct management swales, as necessary.
7. Hand grade any shore escarpments (lips) developed from shore adjustments and plant the shore. Construct goose exclosure fence.
8. Clean, repair, and reseed all disturbed upland areas.

The best time to complete steps 1–4 above is when the ground is dry or frozen. In Maryland this is during the summer and fall months and sometimes in January and February.

Figure 8. Photograph of organic litter and debris that have collected along a restored shore.

Figure 7 illustrates much of this sequence for a project in the Maryland portion of the Chesapeake Bay.

Maintenance

Maintenance to be performed by property owner. The following seven maintenance items should be performed or arranged to be performed by the owners of the properties on which the technique was applied:

1. Water the high elevation vegetation biweekly during the first growing season in the absence of rain.
2. Yearly (in the early spring before plant growth) collect and remove all deposited litter and debris throughout the high elevations of the marsh (Figure 8).
3. Repair, as necessary, the goose exclosure fence for two winters following its installation.
4. Yearly remove or prune tree and shrub species that may volunteer the high marsh and bank so as to maintain at least 6 h daily of direct sunlight throughout the entire marsh.
5. Yearly (in the late spring) check plants for signs of rust infestation and treat as necessary (see next section).
6. Yearly check any constructed stormwater management swales and clean out any deposits of sand or debris in order to maintain functionality.
7. Yearly check the entire project for any signs of problems such as loss of vegetation, unstable sections of restored shore, loss of sand around containment structure(s), scouring on the lee sides of the containment structures, new stormwater erosion gullies, sections of continued bank erosion, etc. If the property owner cannot repair any discovered problem, the contractor should be contacted for advice.

The continued provision for sufficient light, the removal of litter and debris, and the control of plant disease are essential for the long-term success of the technique. As in any natural system, a tidal marsh is not immune to problems. Maintenance must be an ongoing commitment. Generally when problems arise it is because of the property owner's neglect (Trettel 1989). Often, if the property changes hands, the new owners are uninformed about either the work that was done or the required maintenance.

Control of rust. Rust infestation of cordgrass and, to a lesser extent, saltmarsh hay can lead to the death of a tidal marsh particularly if infected early in the growing season before rhizome and new shoot production has occurred. Late-season infestation normally does not permanently impact the marsh.

Evidence of early stages of rust infestation is the appearance of bright orange streaks on the foliage and stems of the plants. After the rust spores died, the orange streaks turn black. Consequently, evidence that the plants had been infected by rust is the appearance of black streaks on the foliage and stems of samples of standing plants or plants picked from the litter (Figure 9).

Three fungicides have been found to be effective for the control of rust on cordgrass and on other grasses during early stages of infestation. Two of the fungicides, Ferbam and Strike 25WP act systemically

Figure 9. The presence of black streaks on the foilage and stems of *Spartina alterniflora* providing evidence of prior infestation by rust.

and the third, Dithane Z-78, is a contact fungicide. At early times of infestation, the infected plants should be sprayed at the manufacturer's recommended rate with one of the systemic fungicides during times of low tide. After the rust has been controlled, the orange color will turn black.

Comparing Costs of the Technique with Those of Other Erosion Control Approaches

Costs are given below for: (1) the technique described herein, (2) the structural alternatives of a stone (rip-rap) revetment, and (3) the structural alternative of a wooden bulkhead. Stone revetments currently are the most commonly used approach for upland bank erosion control throughout the Chesapeake Bay and its tributaries. Bulkheads of any type are currently discouraged by the regulatory agencies.

1. 1993 costs for the technique of filling and grading with no clearing: $50–55 per linear 0.3 m (ft) of shoreline treated.

2. 1993 costs for stone revetment construction with no clearing: $60–65 per linear 0.3 m (ft) of shoreline treated for a revetment 0.9 m (3 ft) high and 1.8 m (6 ft) wide; $75–80 per linear 0.3 m (ft) of shoreline treated for a revetment 1.2 m (4 ft) high and 2.5 m (8 ft) wide.

3. 1993 costs for wooden bulkhead construction: $70–75 per linear 0.3 m (ft) of shoreline treated for a bulkhead 0.9 m (3 ft) high; $90–95 per linear 0.3 m (ft) of shoreline treated for a bulkhead 1.2 m (4 ft) high.

Clearing costs for equipment access to the shore and for shore cleanup for both the technique and stone revetments may add $5–10 per linear 0.3 m (ft) to the costs given above. Such costs normally are not part of those for bulkhead construction, as this work often is done from the water and alongshore trash, litter, and debris (shore cleanup) are thrown behind the bulkhead, as necessary, and buried with fill materials.

Grading of the unprotected upper bank (see Appendix B) adds additional costs to the technique and to stone revetment construction that will vary depending upon site conditions and the extent of grading.

Summary

Restoring the elevations of existing shores to the design standard provided herein controls upland bank erosion by preventing contact of tidal water with the bank face for up to 6–17 years of high tide events in mid-Chesapeake Bay. Marsh construction on the restored shores leads to their stabilization and provides additional protection towards bank erosion during extreme storm events. Full and often surface containment structures are employed to assist with the stabilization of the restored shore as the vegetation communities become established.

The technique has been applied successfully for 21 years in tributaries of the Maryland portion of Chesapeake Bay that have fetches of 1.6 km (1 mi) and less. In addition to reducing water pollution resulting from sedimentation from upland bank erosion, the technique offers further environmental benefits of enhanced fish and wildlife habitat and aesthetics.

The technique, with modifications, should have broad applicability for upland bank erosion control in all bodies of water, including nontidal rivers and lakes.

The technique is economically attractive compared with structural alternatives, such as stone revetments and wood bulkheads. Extending the technique to more exposed shorelines through the use of stone breakwaters and/or sills is feasible, but may be economically prohibitive.

The technique is unique because, unlike structural approaches, it provides shoreline bank erosion control in Chesapeake Bay that continues notwithstanding "effective" rises in sea level. This is because the rate of rise of the marsh peat bank has been found to parallel the "effective" rise in sea level over the past 21 years.

Providing the project sites are selected, the technique carried out, and the projects maintained according to the recommendations provided herein, this technique should be highly effective towards controlling upland bank erosion in the Maryland portion of Chesapeake Bay.

Appendix A. Dealing with the Slope of Existing Shore

Considering the design standard (see earlier section), one can deal with the slope of the restored shore using either one of two approaches:

Approach 1. The design slope of the restored shore is always 10:1, the design shore height is 0.76 m (2.5 ft) above local MHW at the bank face, and the length of the restored shore is variable and always greater than 7.6 m (25 ft). In this case, the restored shore will intercept the existing shore of x:1 slope at distance (y) channelward from the bank face according to equation 1.

$$y = 25 \text{ ft}(x/x - 10)$$

For example: (1) when $x = 10$ or less, the restored shore never intersects the existing shore; (2) when $x = 20, y = 50$ ft; (3) when $x = 40, y = 33.3$ ft; and (4) when $x = 100, y = 27.78$ ft.

Approach 2. The design slope of the restored shore is variable and generally is less than 10:1; the design shore height is 0.76 m (2.5 ft) above local MHW at the bank face; and the design length of the restored shore is 7.6 m (25 ft) channelward of the bank face. In this case, the restored shore will have a slope of y:1 when the existing shore has a slope of x:1, according to equation 2:

$$y = 25/[2.5 + (25/x)]$$

For example: (1) when $x = 10, y = 5$; (2) when $x = 20$, $y = 6.7$; (3) when $x = 40, y = 8$; and (4) when $x = 100$, $y = 9.1$.

In approach 1, for the restored shore to maintain a 10:1 slope its length approaches infinity as the slope of the existing shore steepens from a flat slope to a 10:1 slope. This is unacceptable because: (1) the cost of the technique would increase (more materials would be required) with increasing slope of the existing shore and (2) the increase in wetlands impact (shore filling) with increasing slope of the existing shore would present problems with permitting.

In approach 2, only the slope of the restored shore is affected by the slope of the existing shore. The height and length of the restored shore is fixed at the design standard. This is the approach adopted because: (1) The cost of the technique is not significantly affected by the slope of the existing shore; for practical purposes it is recommended to calculate required materials based upon a existing shore that is flat with a 0% slope. (2) The wetland impacts (extent of fill) are the same for all projects and are independent of the slope of the existing shore. (3) Only existing shores that have slopes that are greater than 10:1 (see earlier section) are excluded from the technique because the slopes of the associated restored shores may then become too great to be stable under the conditions of an otherwise suitable site.

Appendix B. Two Alternatives Involving Grading Upland Bank

Alternative 1: Grading of unprotected upper portion of the bank. Often for aesthetic reasons and to provide bank protection during extreme high tide events, the property owner may wish to grade the unprotected upper bank landward. If the upper bank is open (free of trees and shrubs) and the loss of upland is acceptable, this may be desirable and economical. It is still feasible, but more costly, if the upper bank has a high density of trees and shrubs.

For such work, the recommended design standard is to grade the upper bank landward on no steeper than a 4:1 slope beginning 0.45 m (1.5 ft) below the designed highest elevation of the restored shore (Figure 10). This is to allow room for the restored shore to adjust vertically and horizontally after being subjected to the site's wave climate without exposing the original, more erodable, upland bank face.

The design standard for the restored shore is the same as discussed earlier and in Figure 4 and other design considerations are the same as those provided in previous sections.

Alternative 2: Constructing restored shore through landward and/or channelward sloping of upland bank. This alternative utilizes upland bank sloping to provide on-site materials to restore the shore. If the bank soils are largely medium sized sand (see earlier section), the site suitability, as described in earlier, pertains.

If the bank soils are finer grained than medium sized sand (fine sands, silts, and/or clays) and sloping will be channelward of the bank, a site is suitable for

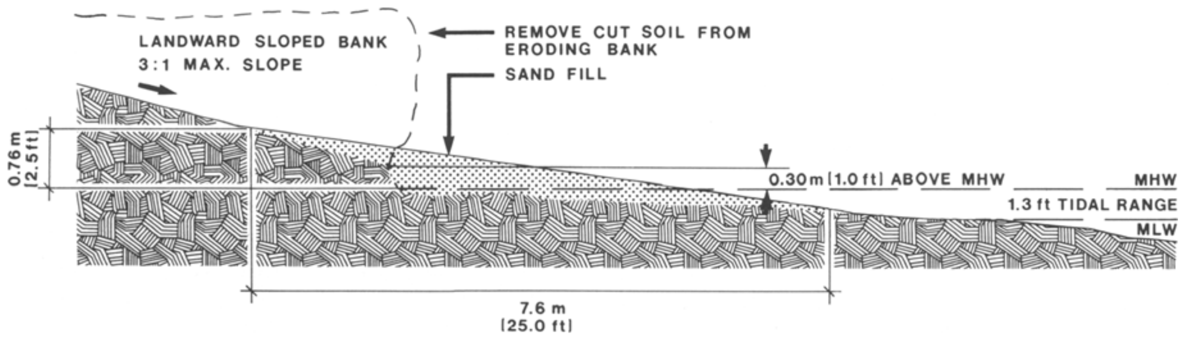

Figure 10. The recommended design standard for the technique when restoring the shore through filling and grading and when grading landward the unprotected upper bank. The tidal range is typical of that for the mid-Chesapeake Bay.

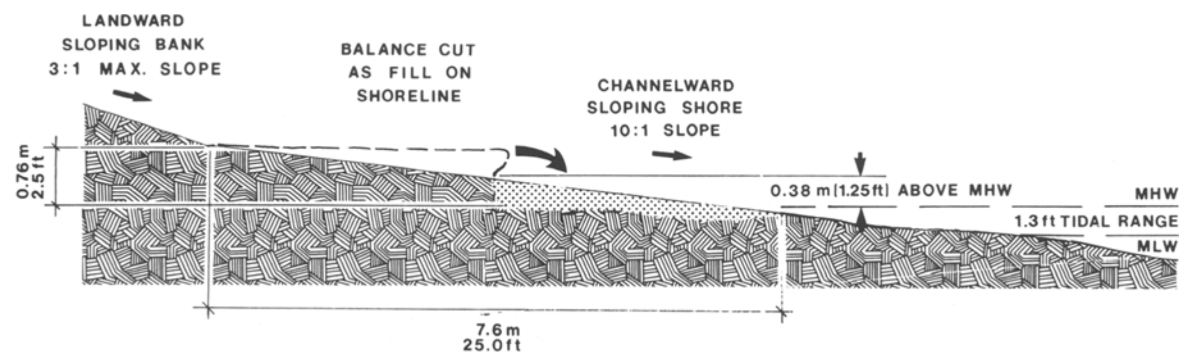

Figure 11. One design option for the technique which combines both landward and channelward sloping of the bank.

the technique only if it is located in an extremely protected area having a maximum fetch of 0.16 km (0.1 mi) and no significant boat activity.

Landward sloping generally is preferred over sloping channelward if the excavated materials can be utilized on site. This is because: (1) The restored shore sediments are not deconsolidated during the grading operation as they are when sloping channelward. Consequently, the restored shore is relatively stable and not subject to the settlement and possible exposure of the original bank face. (2) Whereas county grading and SCS sediment and erosion control permits and Critical Area approval may be required, state and federal wetland permits are not.

One of often several design options for upland bank sloping is to grade the bank landward on a maximum 3:1 slope from the top of the bank to 0.76 m (2.5 ft) above local MHW and to grade channelward on an approximate 10:1 slope from this point to the existing shore (Figure 11). If the sediments throughout the lower half of the restored shore are not sufficiently compacted, their subsequent settlement could expose the original bank face and lead to continued bank erosion.

Containment structures, as described earlier, always will be needed to contain graded materials placed channelward of the bank face. However, such structures generally are needed only at the ends of the project for landward sloping of the bank. This is because the resultant consolidated restored shore soils are less erodable than those resulting from channelward sloping of the bank.

Literature Cited

de la Cruz, A. A., and C. T. Hackney. 1977. Energy value, elemental composition and productivity of *Juncas* tidal marsh. *Ecology* 58:1165–1170.

Dodd, J. D., and J. W. Webb. 1975. Establishment of vegetation for shoreline stabilization in Galveston Bay. MP6-75, US Army Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, 67 pp.

Gallager, J. L., and F. G. Plumley. 1979. Underground biomass profiles and productivity in Atlantic coastal marshes. *American Journal of Botany* 66:156–161.

Garbisch, E. W. 1986. Highways and wetlands: Compensating for wetland losses. US DOT, FHA Report No. FHWA-IP-86-22, 60 pp.

Garbisch, E. W. 1989. Wetland enhancement, restoration, and construction. Pages 261–275 *in* S. K. Majumday, R. P.

Brooks, F. J. Brenner, and R. W. Tiner (eds.), Wetlands ecology and conservation: Emphasis in Pennsylvania. The Pennsylvania Academy of Science, Philadelphia.

Garbisch, E. W., P. B. Woller and R. J. McCallum. 1975a. Salt marsh establishment and development. TM 52, US Army Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, 110 pp.

Garbisch, E. W., P. B. Woller, W. J. Bostian, and R. J. McCallum. 1975b. Biotic techniques for shore stabilization. Pages 405–426 *in* L. E. Cronin (ed.), Estuarine research, Vol II, Geology and engineering. Academic Press, New York.

Good, R. E., N. F. Good, and B. F. Frasco. 1982. A review of primary production and decomposition dynamics of the belowground marsh component. Pages 139–157 *in* V. S. Kennedy (ed.), Estuarine Comparisons. Academic Press, New York.

Hackney, C. T., and A. A. de la Cruz. 1986. Belowground productivity of roots and rhizomes in a giant cordgrass marsh. *Estuaries* 9(2):112–116.

Hardaway, C. S., G. R. Thomas, B. K. Fowler, C. L. Hill, J. E. Frye, and N. A. Ibison. 1985. Results of the vegetative erosion control project in the Virginia Chesapeake Baysystem. Pages 144–158 *in* F. J. Webb, Jr. (ed.), Proceedings of the twelfth annual conference on wetlands restoration and creation. Hillsborough Community College, Tampa.

Knutson, P. L. 1977. Planting guidelines for marsh development and bank stabilization. Coastan Engineering Technical Aid No. 77-3. US Army Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, 21 pp.

Knutson, P. L., and W. W. Woodhouse, Jr. 1983. Shore stabilization with salt marsh vegetation. Special Report 9. US Army Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir. 95 pp.

Knutson, P. L., R. A. Brochu, W. N. Seelig, and M. Inskeep. 1982. Wave damping in *Spartina alterniflora* marshes. Wetlands 2:87–104.

Roman, C. T., and F. D. Daiber. 1984. Aboveground and belowground primary production of two Delaware Bay tidal marshes. *Bulletin of the Torrey Botany Club* 111:34–41.

Sharp, W. C., and J. Vaden. 1970. Ten-year report on sloping techniques used to stabilize eroding tidal river banks. *Shore and Beach* 38:31–35.

Stroud, L. M. 1976. Net primary production of belowground material and carbohydrate patterns of two height forms of *Spartina alterniflora* in the North Carolina marshes. PhD thesis. North Carolina State University, Raleigh, North Carolina, 140 pp.

Trettel, J. R. 1989. Evaluation of constructed and vegetated shorelines (CVS) for erosion control in low energy areas of the Chesapeake Bay. MS thesis. Duke University, Durham, North Carolina, 89 pp.

US Department of Commerce, National Oceanic and Atmospheric Administration. Summary of monthly tidal extremes: Solomons, MD (857–7330) 1937–1990 and Annapolis, MD (857–5512) 1928–1991. Silver Spring, Maryland.

Valiela, I., J. M. Teal, and N. Y. Persson. 1976. Production and dynamics of experimentally enriched salt marsh vegetation. *Limnology and Oceanography* 21:245–252.

Webb, J. W., and J. D. Dodd. 1976. Vegetative establishment and shoreline stabilization, Galveston Bay. Technical Paper 76-13. US Army Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir. 77 pp.

Woodhouse, W. W., Jr., E. D. Seneca, and S. W. Broom. 1974. Propagation of *Spartina alterniflora* for substrate stabilization and salt marsh development. Technical Memorandum 46. US Army Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir. 155 pp.

Woodhouse, W. W., Jr., E. D. Seneca, and S. W. Broom. 1976. Propagation and use of *Spartinal alterniflora* for shoreline erosion abatement. Technical Report No. 76-2. US Army Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir. 72 pp.