# Suwannee River Water Management District
# Shoreline Erosion Control Guide

## Effective [DATE]

(Incorporated by Reference in Rule 40B-4.1090, F.A.C.)

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## 1.0 INTRODUCTION

This document was compiled by Taylor Engineering, Inc. in May 2020, under contract 2019-034, and submitted to the Suwannee River Water Management District (District) to provide single-family landowners with a guide for reducing shoreline erosion on properties located along Works of the District (WOD) rivers listed in Rule 40B-4.3000, Florida Administrative Code (F.A.C.) (see Figure 1.1).

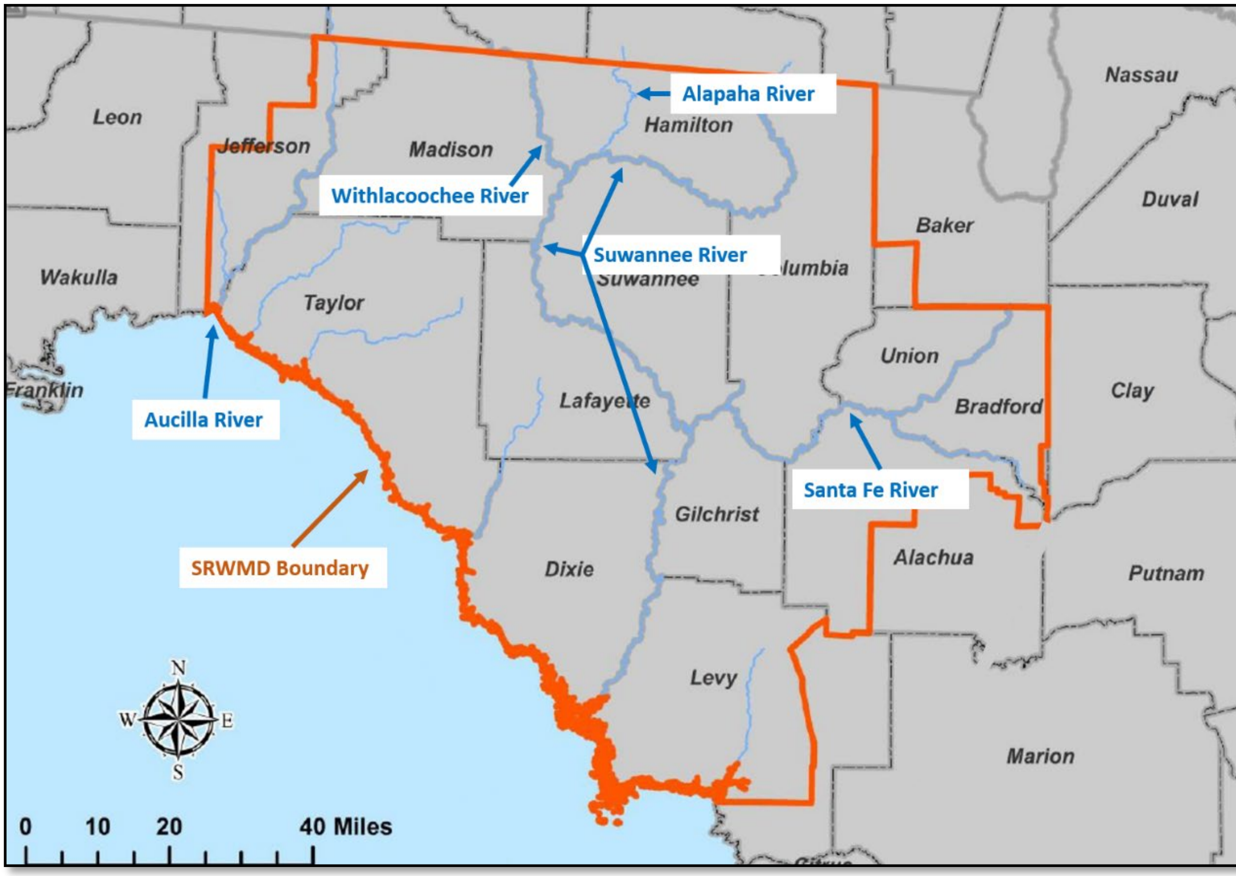


**Figure 1.1** Works of the District Rivers and District Boundaries

This guide is intended to assist landowners with making informed decisions on how to protect their property from erosion with practical shoreline erosion control solutions. The guide will enable landowners to be proactive in protecting their property, streamlining the regulatory review process, and expedite implementation of shoreline erosion solutions. This guide provides fourteen options for reducing erosion and stabilizing banks ranging from low-cost installations to complex solutions that require professional engineering design. These options are organized into three general categories:

- Non-Engineered Shoreline Stabilization with Vegetation;
- Hybrid Shoreline Stabilization; and
- Hardened Engineered Shoreline Stabilization

The alternatives in this guide may be used along lakes, rivers and other waterbodies that are not along WOD rivers; however, these areas may fall under the jurisdiction of other agencies with different permitting requirements. Alternatives presented in this guide, may be used by landowners within WODs which are not single-family, however, the type of permit may vary from those listed in Section 1.2.

A brief description of the advantages, applicable site characteristics, approximate service life, installation techniques, and approximate unit cost have been provided for each erosion control/stabilization alternative. No design work was conducted in the preparation of this guide; therefore, neither the District nor Taylor Engineering, Inc. will assume responsibility for the failure of recommended systems permitted and constructed by landowners using this guide. The mention or depiction of a specific proprietary erosion control product, manufacturer, or supplier should not be construed as an endorsement by the District or Taylor Engineering, Inc. Multiple alternatives may be implemented on a project to control erosion or stabilize banks under one District authorization. However, modifying these alternatives may result in the need for a different permit type and additional supporting documentation. In some cases, additional local, state and/or federal criteria, permits or authorizations may be required (see Section 1.2); and the District strongly recommends that property owners contact their local governments and applicable state and federal agencies prior to land preparation or construction.

## 1.1 Typical Site Characteristics

Most riverbanks are vegetated to varying degrees. Washouts, or areas of erosion, are present along much of the riverbanks but particularly in unvegetated areas. Erosion and scouring, which are common along riverine shorelines, undermine the bank and underlying soils, and often expose tree roots. Continued scouring could result in loss of bank stabilization and can threaten structures as well as the general ecosystem. Once erosion has been identified, landowners are encouraged to implement shoreline protection measures proactively.

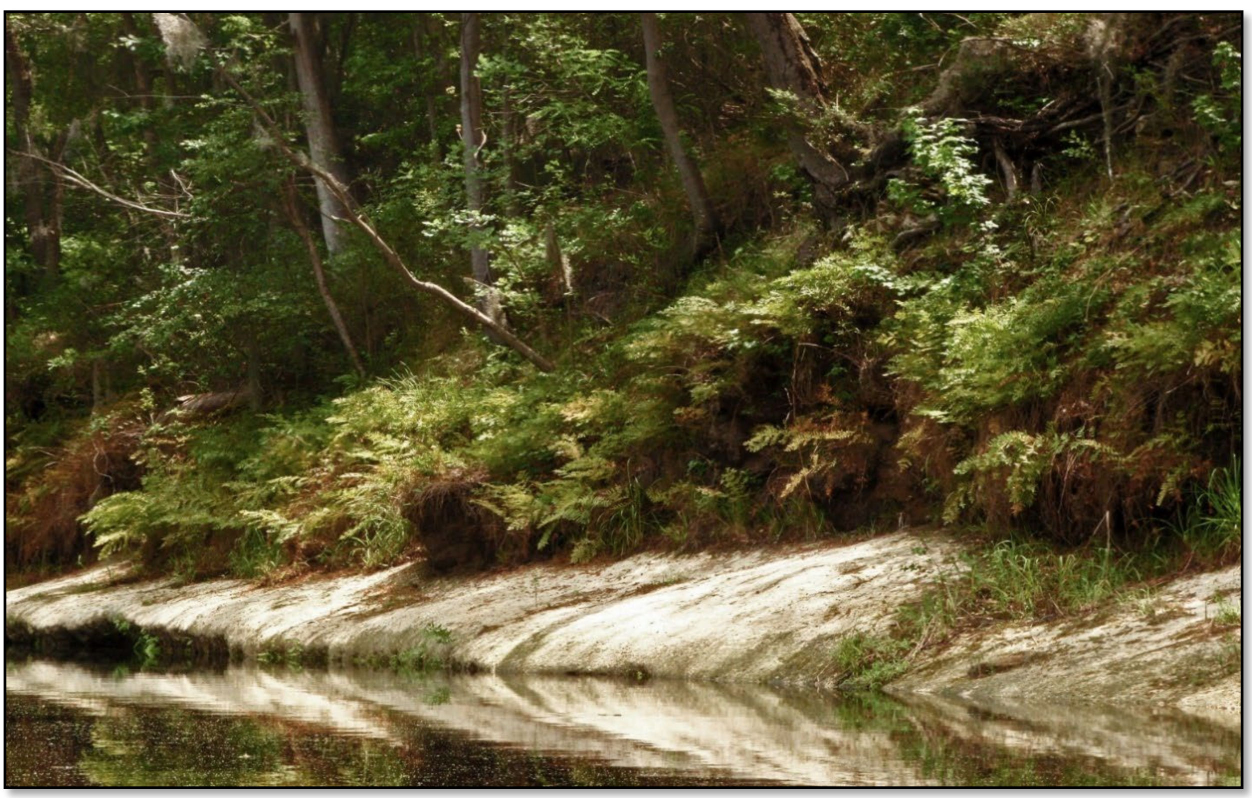

**Figure 1.2** Example of Typical Shoreline Erosion Conditions (Gar Pond Tract)

The unique slope, soils, erosion type, and proximity to adjacent properties characteristics of each site should be evaluated before implementing any type of shoreline stabilization.

### *1.1.1 Slopes*

Riverbank slopes can range from flat to nearly vertical. Certain erosion control alternatives perform better on particular slopes, and failing to select an appropriate solution for your property might compromise project effectiveness and success. To aid in the selection of the appropriate alternative, this guide classifies slopes based on horizontal unit (H) to vertical unit (V) ratios as shown in Table 1.1 below. Flat to gentle slopes, for example, have four or more feet in horizontal distance to every one foot of vertical distance. Figures 1.3 through 1.5 help to identify the slope on your property.

**Table 1.1** Slope Classification

| Type of Slope | Percentage | H:V |
|---|---|---|
| Flat to Gentle | < 25% | < 4:1 |
| Moderate | 25% to <80% | 4:1 to 1.25:1 |
| Steep to Vertical | 80 to 100% | 1.25:1 to 1:1 |

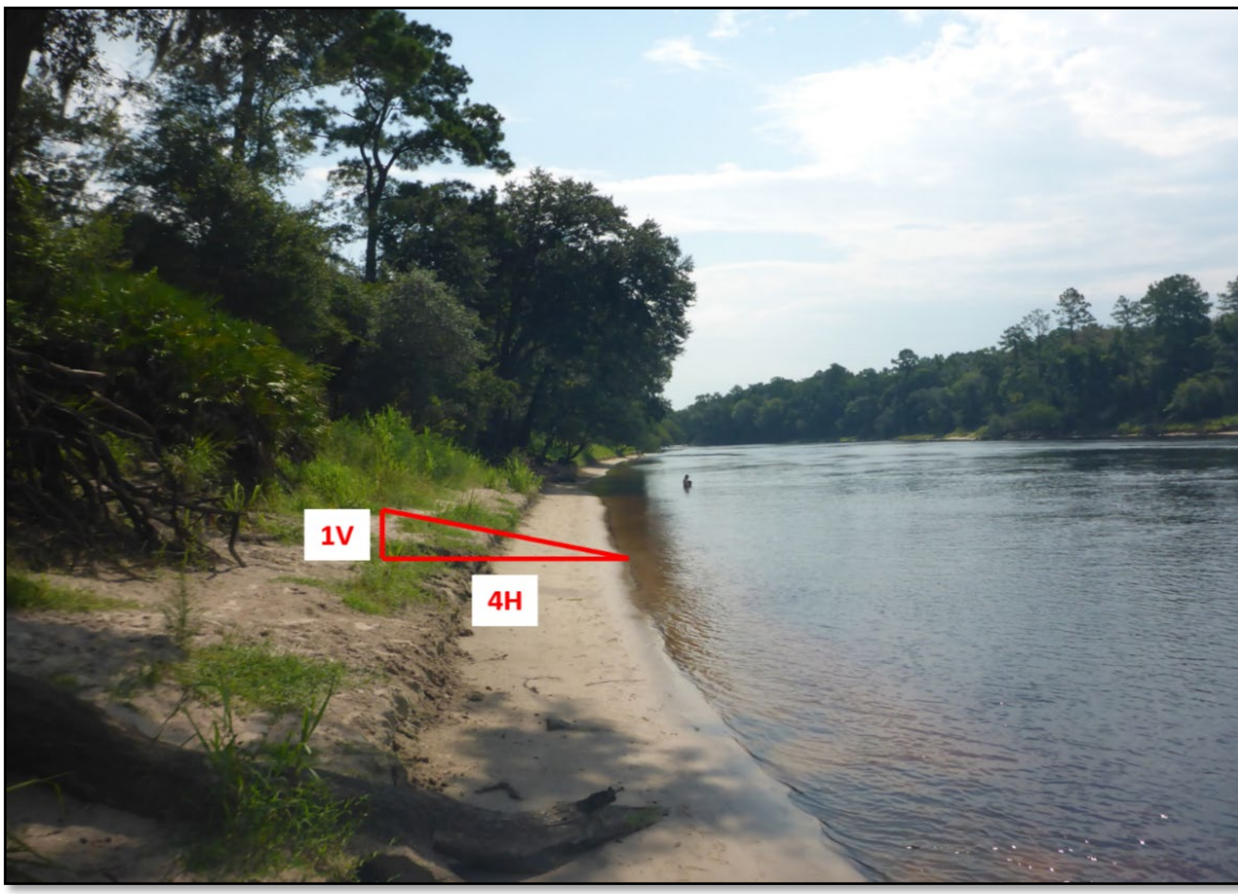


**Figure 1.3** Example of a Gentle Slope < 25% (Little River Spring Park)

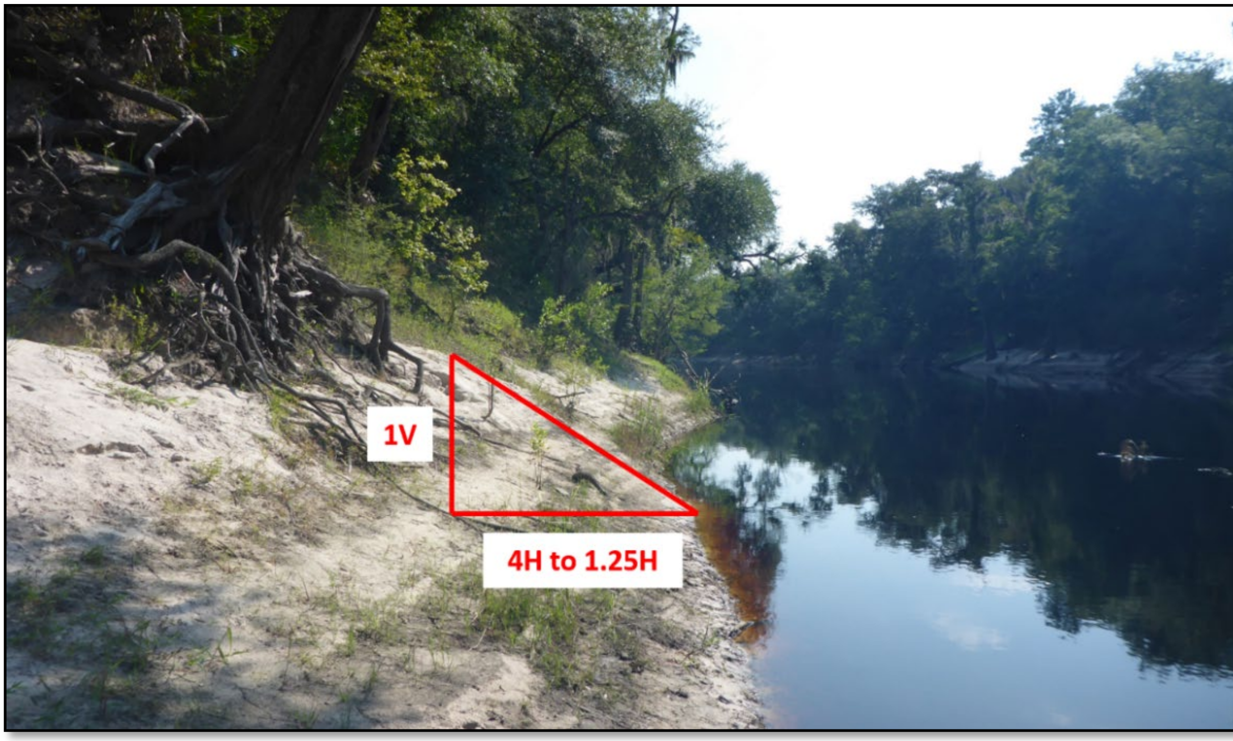


**Figure 1.4** Example of a Moderate Slope between 25% and 80% (Stephen Foster State Park)

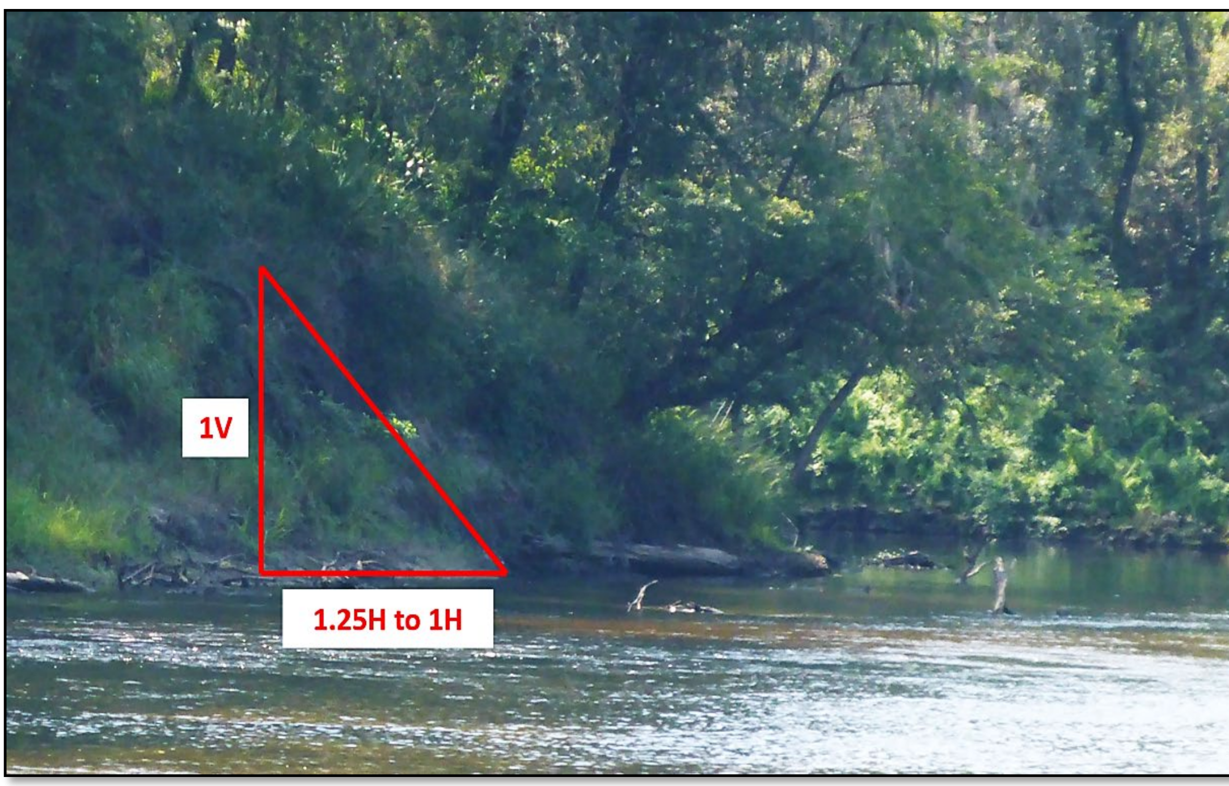


**Figure 1.5** Example of a Steep Slope between 80% to 100% (Pot Springs)

#### *1.1.2 Soil*

Site soils can range from loose (soft) to consolidated (hard). Loose soils such as sand, peat, and silt, erode faster than consolidated soils such as weathered limestone, rock, and clay. Stabilizing loose soils may require engineering to protect the bank from slope failure before the erosion alternative is installed. Consolidated soils are usually more resistant to shoreline erosion and may not require bank stabilization.

#### *1.1.3 Erosion Types*

The most common factors that contribute to riverbank erosion are manmade alterations, water current, wind, waves, boat wakes, and upland runoff from heavy rains. Rainfall produces four of the most common types of soil erosion, defined as follows:

- Splash erosion – results from impact of a falling raindrop;
- Sheet erosion – typically caused by upland runoff wherein the water sheet flows to lower ground;
- Rill erosion – describes erosion that takes place as runoff develops into discrete streams; and
- Gully erosion – the stage in which soil particles are transported through large channels, carrying water for brief periods of time during rainfall but appear as small valleys or crevasses in dry seasons.

#### *1.1.4 Erosion Control Alternative Aesthetics*

Aesthetics is often an important factor when considering the shoreline stabilization alternative, with natural vegetative alternatives generally preferred. Natural vegetative options are sustainable and durable stabilization alternatives if resilient plant species suited for shoreline stabilization, rather than traditional landscaping, are selected. Site conditions will dictate whether use of vegetation alone is appropriate or if supplemental reinforcement may be needed.

#### *1.1.5 Effects on Adjacent Properties*

Installation of shoreline stabilization options without the consideration of adjacent properties may result in unanticipated shoreline damage and even increased erosion. Natural shoreline transitions, such as changes in slope, or the presence of structures generally do not align with property lines; and consideration of these transitions avoids adverse impacts to neighboring properties. District regulatory staff may provide property owners with suggestions to minimize potential impacts to adjacent properties as part of the pre-application meeting; however, advisement from consultants, contractors, or other professionals is preferred.

### 1.2 Permitting and Other Requirements

Scheduling an onsite pre-application meeting with District regulatory staff is highly recommended before implementing any of the alternatives in this guide. All of the bank stabilization alternatives, whether listed in this guide or not, will require a WOD permit and a pre-application meeting makes the permitting process more efficient. The alternatives in this guide are also intended to address stabilization of existing riverbanks. Restoring riverbanks to their former extent within the previous five years is also permissible if the landowner provides a signed and sealed survey indicating the shoreline's past location and date.
Alternatives in this guide may be applied to a landowner's entire shoreline or to small discontinuous areas, such as to stabilize a single tree. District regulatory staff will compare proposed alternatives not listed in this guide to those contained in the guide and categorize them accordingly. Bank stabilization proposed on properties with activities previously permitted by the District will be processed as modifications to the existing permit. See Rule 40B-4.3020, F.A.C., for permit application content requirements.

For properties with no previous District permits, non-engineered alternatives presented in this guide may be authorized under a Noticed General (NG) WOD Permit, which do not require engineering plans or calculations. Additionally, to qualify for a NG WOD Permit, the proposed shoreline application must not be higher in elevation or waterward of the existing bank prior to the occurrence of the erosion scar, or as observed on adjacent riverbanks. These non-engineered alternatives may require higher levels of permitting if the NG WOD Permit criteria found in Rule 40B-4.3010, F.A.C., are exceeded. Exceedances include, but are not limited to, projects that propose volumes of fill or redistributed material greater than NG WOD thresholds, projects that result in impacts to wetlands or other surface waters, or other activities that do not directly align with NG WOD criteria.

Hybrid alternatives may be implemented by landowners, with the assistance of a licensed contractor, under a General WOD Permit issued by the District. Engineered alternatives requiring a General WOD must be submitted as signed and sealed plans and calculations submitted to the District by a Florida registered Professional Engineer. For properties that have steeper slopes, a more aggressive engineered solution may be necessary to stabilize and protect upland property, which may require an Individual Environmental Resource Permit (ERP) as set forth in Chapter 62-330, F.A.C.
Best Management Practices (BMPs) for erosion and sedimentation control are required for installation of all alternatives to treat, reduce, and/or prevent polluted runoff into the river during construction. All BMPs must be in place prior to the start of construction. Examples of acceptable BMPs include, but are not limited to, sheet piled walls, turbidity barriers, and silt fences. For information regarding the proper erosion and sedimentation control BMPs and their applications, please refer to the *Florida Stormwater, Erosion and Sediment Control Inspector's Manual*. BMP installation may also be discussed as part of the pre-application meeting.

For proposed work below the proprietary Ordinary High Water Line (OHWL), as determined by a licensed professional, a Submerged State Lands (SSL) authorization may be required. SSL authorizations often require the submittal of additional information such as boundary and/or topographic surveys, the safe upland line determination, riparian rights lines, and a site plan showing preempted area(s) and riparian rights setbacks. In most cases, an SSL authorization may be issued by the District, through a Consent of Use authorization, if proposed activities meet the requirements set forth in Chapters 18-20 and 18-21, F.A.C. Exceedance of the Consent of Use thresholds contained in these Chapters may require an SSL lease. For projects that require an ERP, the District ERP authorization will contain WOD criteria as part of the ERP. The project must comply with the requirements of both Chapters 40B-4 and 62-330, F.A.C., and the proposed project may require submittal of additional information or documentation required in these Chapters.

An ERP may be required for projects that include wetlands or other surface waters as determined by the State of Florida, which are defined in Chapter 373, Florida Statutes (F.S.) and Chapter 62-340, F.A.C. Wetlands are generally defined as those areas that have sufficient hydrology to support a dominance of wetland plant species. Examples of wetlands include, but are not limited to, cypress swamps, marshes, and similar habitats. Wetlands are protected by State regulatory agencies and cannot be adversely impacted without authorization, regardless of their location or proximity to the top of riverbank. Minimal wetland impacts, as determined by the District, may qualify for an exemption pursuant to Subsection 373.406(6), F.S. However, most wetland impacts require mitigation, which may consist of the purchase of mitigation bank credits, onsite wetland preservation, wetland restoration, or in-kind wetland creation. This guide does not contain comprehensive information regarding wetland identification, regulation, and/or permitting. Precise wetland delineation can be complicated and may require the assistance of

District regulatory staff and/or a private environmental consultant. Wetland mitigation can be very costly and time consuming; therefore, it is strongly recommended that wetland impacts be avoided or minimized.

For projects involving work in wetlands or other surface waters as determined by federal criteria, a U.S. Army Corps of Engineers (USACE) authorization may also be required. In most cases a Nationwide Permit would be required under Section 10 of the Rivers and Harbors Act, or Section 404 of the Clean Water Act. However, a higher-level authorization may be required if thresholds contained in the above Acts are exceeded. Landowners must make application directly with the USACE for this authorization. More information about USACE permitting may be found online at https://www.saj.usace.army.mil/. **Failure to obtain USACE authorization prior to construction could subject you to federal enforcement action.**

Although uncommon, some projects may require a National Pollutant Discharge Elimination System (NPDES) permit. If the proposed work meets the NPDES thresholds, a permit from the Florida Department of Environmental Protection is required. More information about NPDES permits may be found online at https://floridadep.gov/water/stormwater. **Failure to obtain a NPDES permit prior to construction could subject you to enforcement action by that agency.**

## 2.0 NON-ENGINEERED "SOFT" SHORELINE EROSION CONTROL ALTERNATIVES

This section of the guide provides landowners with non-engineered river shoreline erosion control alternatives. The non-engineered 'soft' shoreline stabilization alternatives described below include a general description, alternative advantages/disadvantages, suitable slope applications, approximate design service life, installation techniques, and estimated installation costs. The estimated material and installation costs were developed using manufacturer quotes and are subject to change based on availability of materials, site location/accessibility, and other factors; and do not include erosion and sedimentation BMP installation costs. Similarly, the manufacturers' statement of design life for a given product and/or material may vary greatly from site-to-site based on intensity of water current, frequency of storm events, quality of materials, quality of installation, and post-construction maintenance. Existing site conditions will influence which alternative(s) are viable and most appropriate for each property. Landowners are encouraged to obtain multiple price quotes and consult with materials manufacturers and installation contractors prior to the start of work.

### 2.1 Native Vegetation Planting

Seeding or planting native vegetation along the shoreline may be a cost-effective solution against erosion. Vegetation often performs best on gentle slopes and may not perform well in areas that are under water for long periods of time. The development of strong root systems is critical to support retention of the soil structure along the riverbank. Benefits provided by shrubs and trees with deep roots include improved bank stability, creation of wildlife habitat, and slowing of stormwater flow to help reduce the frequency and severity of washouts. As the vegetation matures, increasing in size and ground cover, the root systems strengthen further reinforcing shoreline stability.

Native vegetation should be carefully selected, and landowners are encouraged to plant a mix of native trees, shrubs, flowers, ferns, and grasses at varying heights to provide an intertwined mix of root structures. During the pre-application meeting, District regulatory staff can provide recommendations of native plants beyond those listed below. Although there is no requirement to plant the recommended vegetation, invasive or exotic vegetation is prohibited from being used for bank stabilization. Appropriate vegetation types can be identified under four zones:

- Bottomland **-** Bottomland is a frequently flooded swamp habitat, with a thick canopy strata (tall trees), thinner subcanopy (small trees and shrubs), and moderately thick groundcover (herbs, grasses, etc.). Standing water may be present. Water stains may be visible on tree trunks showing the typical high water level. Common species include bald cypress, green ash, elm, red maple, sweetgum, buttonbush, Virginia willow, narrow blue-eyed grass, and false indigo
- Floodplain - Like bottomland, floodplain habitat is often inundated (flooded). It differs from bottomland by having a thinner canopy, a thicker subcanopy, and very little groundcover. The lack of groundcover and the presence of morphological adaptations (such as buttressing and adventitious roots) indicate that this habitat is periodically deeply inundated when the river floods. Common species include bald cypress, laurel oak, elm, red maple, water locust, buttonbush, and swamp privet.
- High Bluff **-** These are upland forests with high bluff banks at least 10 feet above the normal level of the river. High Bluff is the most common upland habitat type adjacent to the banks along the upper Suwannee, Withlacoochee Rivers, and Santa Fe River. Common species include live oak, water oak, laurel oak, hackberry, red mulberry, American plum, sweetgum, pignut hickory, sparkleberry, sebastiana, false indigo, fringe tree, deerberry, saw palmetto, and variable-leaf witchgrass.
- Low Bluff – These are areas that appear to be upland (not meeting the state definition of wetlands) and that have a low but definite bank between 4 and 10 feet above the OHWL of the river. Most of the species that occur in high bluff habitat also occur here. Due to the lower elevation of this habitat type, it includes some wetland plants not observed in high bluff sites, such as the understory tree hornbeam.

Installation of this alternative requires only planting and may be implemented without soil grading. Planting schematics will vary depending on the vegetation chosen, density of coverage needed, and level of erosion. Choose aquatic vegetation if the site may be submerged for extended periods of time. Vegetation is most vulnerable immediately after planting since newly planted vegetation often has shallow root systems and can be damaged during strong winds and flooding events, requiring replanting/re-seeding. Landowners should perform continual maintenance to account for growing seasons and needed pruning, or vegetation loss/damage due to flooding, storm events, or other factors. With proper maintenance, native vegetative planting can last indefinitely. This alternative may be implemented independently or combined with other alternatives.

**Table 2.1** Planted Vegetation Design Criteria

| | |
|---|---|
| **Site Characteristics** | Gentle to Moderate Slopes |
| **Avg. Estimated Service Life** | N/A |
| **Approx. Installed Cost Using Florida Native Species to Cover 10 ft. in Width** | $10/LF<br>$1,000/100 FT |

**Figure 2.1** Example of Native Vegetation (Twin Rivers State Park)

## 2.2 Invasive Exotic Vegetation

Eradicating invasive exotic vegetation management is a key strategy in protecting natural areas and newly planted native vegetation. Invasive exotic plants are termed "Category I" when the plants displace native plant communities, change plant community structures or ecological functions, or hybridizing with native plant species. This category is dependent solely on documented ecological damage, not the economic severity or geographic range of the problem. "Category II" invasive exotic vegetation may have widespread abundance or frequency but have not yet altered plant communities to the extent shown by Category I species (see Table 2.2). These species may become Category I if ecological damage is demonstrated.

When invasive exotic vegetation is no longer controlled by the weather, diseases, or pests found in their native range, they often out-grow and replace native species. When native species are displaced, the fish and wildlife that depend on them are also affected. The replacement of native species by invasive exotic vegetation can also reduce biodiversity, alter fire frequency or intensity, or change water flow. Hydrilla verticillate, for example, is a Category I invasive exotic submerged aquatic plant. Hydrilla can choke waterways making it impossible for boats to travel or water to flow downstream; and, when it grows uncontrollably, it can affect water quality and reduce fish populations. Lygodium japonicum (Japanese climbing fern) is also a Category I invasive exotic plant (Figure 2.2). Japanese climbing fern is a vine that climbs over native shrubs and trees forming a dense canopy that shades out and overtakes native plants. When this occurs, native plants are no longer able to provide habitat, food for wildlife, or soil stabilization. A list of invasive plant species and a link to the exotic pest plant database are available at the Florida Exotic Pest Plant Council's website (www.fleppc.org).

**Table 2.2** Common Florida Invasive Exotic Species

| **Category I** | **Category II** |
|---|---|
| Air Potato | Alligator Weed |
| Brazilian Pepper | Caesar's Weed |
| Camphor Tree | Chinaberry |
| Chinese Privet | Chinese Brake Fern |
| Chinese Tallow | Chinese Wisteria |
| Cogongrass | Elephant Ear |
| Glossy Privet | Golden Bamboo |
| Japanese Climbing Fern | Paper Mulberry |
| Japanese Honeysuckle | Tung Oil Tree |
| Kudzu | Wax Begonia |
| Mimosa | |
| Nandina | |
| Natal Grass | |
| Skunk Vine | |
| Sword Fern | |
| Torpedo Grass | |
| Tropical Soda Apple | |
| Wild Taro | |

**Figure 2.2** Japanese Climbing Fern (Exotic Invasive)

## 2.3 Coir Logs

Coir logs are an erosion control alternative designed for use in combination with seeding or planting as described in Section 2.1. Coir logs are densely packed rolls that are staked to provide protection to the toe (bottom) of the riverbank without disturbing the existing soil conditions. Coir logs consist of clean natural fibers, typically coconut or pine straw, rolled-up to form elongated log features. The fibers are densely packed and held together with a jute mesh forming a substrate for plant growth. Coir logs are not to be confused with coir wattles, which are less dense and designed to capture sediment in low energy environments, such as lakes with minimal boat wakes. Coir logs are typically available in 10- and 20-foot lengths and can be joined using twine. Most commercial coir logs are available in diameters of 12 inches, 16 inches, or 20 inches.

Coir logs are typically used at sites requiring minor slope stabilization while seedlings or immature plantings grow and take root. For best results, vegetation should be seeded or planted inside the logs or on either side of them to help reduce bank erosion. Core logs are designed to last for two to five years. After which, the natural fiber logs gradually bio-degrade as the vegetation has matured and established. Coir logs are typically installed manually with minimal subsurface soil preparation on gentle to moderate slopes. They can be installed along the face of the slope or used near the toe of the slope and secured with biodegradable stakes (spaced an average of three feet on centers) where the erosion may be more significant. Some installations can be stacked and anchored two logs high for moderate slope conditions. Coir logs may provide shoreline protection from boat wakes, but other methods should be evaluated when strong currents are expected. Maintenance will be needed if the coir logs are damaged by severe weather. The remainder of the upper slope should be vegetated using native species planted in accordance with Section 2.1.

**Table 2.3** Coir Logs Design Criteria

| | |
|---|---|
| **Site Characteristics** | Gentle to Moderate Slopes |
| **Avg. Estimated Service Life** | 2 to 5 Years |
| **Approximate Installed Cost for One Row of Logs (not including vegetation or seeding)** | \$20/LF (source: RH Moore & Assoc., Inc.)<br>\$2,000/100 FT |

**Figure 2.3** Example of Coir Logs Installation

## 2.4 Erosion Control Blankets

Erosion control blankets are another soil stabilization system used to help reinforce the soil in combination with vegetation seeding or planting as described in Section 2.1. This product is designed to help enhance vegetative growth by interlocking the immature plant root systems and holding soil in place. These blankets retain soil moisture and provide limited erosion protection until the vegetation matures. Erosion control blankets are usually composed of a coconut fiber matrix, agricultural material, or pine straw. They are available in a single- or double-net combination, depending on the tear strength required. The nets are often made of jute or a biodegradable polypropylene that binds the natural fibers. Erosion control blankets typically last for a period of two years depending on site conditions. Gradually, the blankets bio-degrade and are harmless to the surrounding environment.

Installation of this alternative requires clearing the project area of any debris, rocks, roots, and invasive plants. Depending on the type of erosion present, minor grading above the OHWL and a small amount of fill may be necessary to provide a smooth, level surface prior to installation. If fill and grading are required, compaction may be achieved with a small manual tamper. A uniform slope along the bank helps prevent flow acceleration due to uneven bank slopes and allows for consistent anchoring to secure the blanket in place. Once the site has been prepared, seeds should be planted before laying the blanket. Moderate slopes may require positioning the blankets perpendicular to the river flow, in accordance with manufacturer specifications. The blankets are held in place with wooden stakes to help in the successful establishment of the seeds or planted vegetation. This alternative is a simple, low-cost supplement to the vegetation-only alternative. The material is vulnerable to high amounts of runoff and moderate flooding events, and maintenance will be needed if severe weather damages or removes the blankets before vegetation has been established.

**Table 2.4** Erosion Control Blanket Design Criteria

| | |
|---|---|
| **Site Characteristics** | Gentle to Moderate Slopes |
| **Avg. Estimated Service Life** | 2 Years |
| **Approx. Installed Cost to Cover a 10 ft. in Width (not including vegetation)** | $8/LF (source: RH Moore & Assoc., Inc.)<br>$800/100 FT |

**Figure 2.4** Example of Erosion Control Blankets

### 2.5 Reinforcement Mats

Reinforcement mats are similar in application to erosion control blankets and intended for use in combination with seeding or planting as described in Section 2.1. Reinforcement mats help to anchor the soil and promote vegetation stability and growth. These mats are heavier and may be applied on slightly steeper slopes than erosion control blankets. Reinforcement mats are made from a three-dimensional synthetic material such as polypropylene, polyester, polyethylene, nylon, polyvinyl chloride, glass, or various mixtures of these materials to increase product longevity. The materials are often UV-resistant and woven into a uniform configuration like a mesh. Also known as turf reinforcement mats, they are designed to be covered with sod, or other vegetation. The mat material has a high resistance to breakage/tearing, comes in rolls, and may be available in different colors (like green, black, or tan). This product provides a stronger cross-section than the natural fiber blanket alternative and may withstand higher water flow velocities. Although the synthetic materials used to manufacture the reinforcement mats may have an estimated design life of up to 50 years, the actual service life of the material may only be 5 to 15 years, depending on site application, maintenance, and vegetation density.

Installation of this alternative requires clearing the project area of any debris, rocks, roots, and invasive plants. Depending on the type of erosion present on the site, minor grading above the OHWL and a small amount of fill may be necessary to provide a smooth, level surface prior to installation. If fill and grading are required, compaction may be achieved with a small manual tamper. A uniform slope along the bank face helps prevent flow acceleration due to uneven bank slopes and allows for consistent anchoring to secure the mats in place. Once reinforcement mat placement area is properly prepared, the mats can be laid out on land surface with the mat perimeters buried in a trench 6 to 12 inches deep (including the waterward toe) and backfilled to secure the edges and provide anchoring using the trench material. The waterward side of the mat should be anchored above the OHWL. However, when no other viable options exist, it may extend waterward beyond the OHWL and be submerged. In cases where the mat extends below the OHWL, rip rap should be used to fill the waterward trench and prevent erosion. U-shaped staple or J-hook anchors are then used to secure the interior of the mat. The mats are then filled with fertile soil and seeded or planted with container-grown native plants. Because of this product's buoyancy, proper anchoring and site selection are critical to ensure successful vegetation growth and effective shoreline stabilization. Maintenance for the reinforcement mats is recommended to ensure vegetation and soil remain stable; however, maintenance of the mat material should not be necessary. In the event vegetation and/or soil are displaced from a mat section, the reinforcement mat can be re-buried in soil and replanted.

**Table 2.5** Reinforcement Mat Design Criteria

| | |
|---|---|
| **Site Characteristics** | Moderate to Steep Slopes |
| **Avg. Estimated Service Life** | 10 Years |
| **Approximate Installed Cost to Cover 10 ft. in Width (not including anchor rock or vegetation)** | $25/LF (source: RH Moore & Assoc., Inc.)<br>$2,500/100 FT |

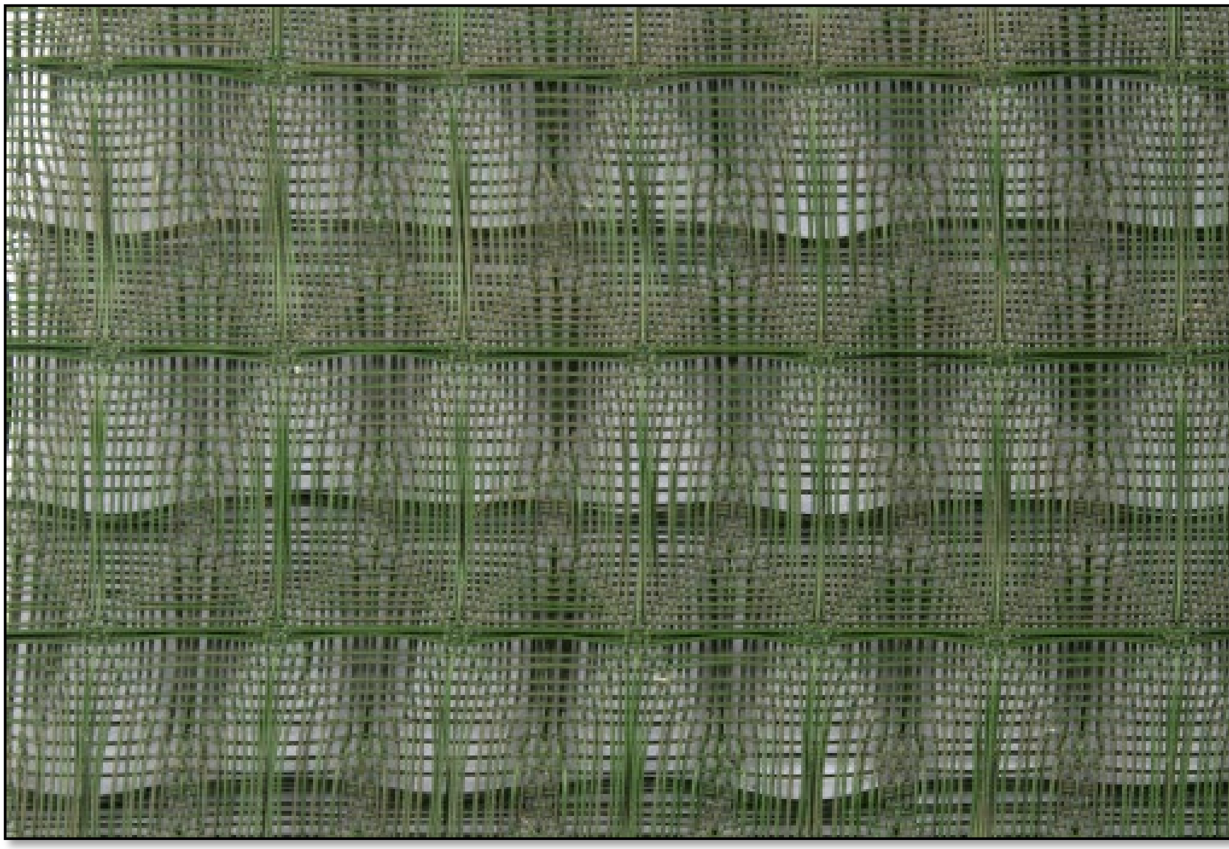

**Figure 2.5** Example of Reinforcement Mat

## 2.6 Geogrid Mat

Another type of reinforcement mat alternative is the geogrid mat. This mat is designed for use in combination with native vegetative seeding or planting as described in Section 2.1. The product is fabricated using synthetic material such as polypropylene, polyester, polyethylene, nylon, or a mixture of these material to increase product longevity. Geogrid mats have similar characteristics, advantages, application, and installation procedures as those outlined for the reinforcement mat in Section 2.4, however, this product includes wider openings, ranging from two to four inches, to accommodate larger plants and root systems. Additionally, the geogrid mat product has significantly greater tensile strength, allowing it to be used more effectively on steeper riverbanks. Some geogrid mats are built with nylon materials that reduce the buoyancy associated with reinforcement mats. This alternative also provides better stabilization for vegetated slopes that are exposed to higher currents and can accommodate larger vegetation root systems. Installation techniques and maintenance are similar to the reinforcement mats.

**Table 2.6** Geogrid Mat Design Criteria

| | |
|---|---|
| **Site Characteristics** | Moderate to Steep Slopes |
| **Avg. Estimated Service Life** | 10 Years |
| **Approximate Installed Cost to Cover 10 ft. in Width (not including anchor rock or vegetation)** | \$25/LF (source: RH Moore & Assoc., Inc.)<br>\$2,500/100 FT |

**Figure 2.6** Example of Geogrid Mat (source: RH Moore)

## 3.0 HYBRID SHORELINE EROSION CONTROL ALTERNATIVES

This section of the guide outlines examples of hybrid stabilization alternatives for river environments, which combine structural components with naturally sustainable vegetative features. These alternatives offer increased reinforcement and a potentially longer service life when compared to non-engineering alternatives.

The hybrid alternatives described below include advantages as well as the range of suitable slopes, approximate design service life, installation techniques, and estimated installation costs. The material and installation costs were estimated using manufacturers quotes and are subject to change based on availability of materials, site location/accessibility, and other factors; and do not include erosion and sedimentation BMP installation costs. Similarly, the manufacturers' statement of design life for a given product and/or material may vary greatly from site-to-site based on intensity of water current, frequency of storm events, quality of materials, quality of installation, and post-construction maintenance. All alternatives detailed in this section are intended to be coupled with native vegetation seeding or planting as outlined in Section 2.1.

The District WOD permit application for the alternatives outlined in this section may be prepared by a licensed contractor if designated as the property owner's agent. However, the site plan, zero-rise, and survey must be signed and sealed by a registered professional. The installation of these alternatives generally requires the use of heavy machinery, and it is the contractor's responsibility to ensure that impacts to the environment and adjacent properties are minimized. Specifically, the selected alternative must:

1. Adhere to the installation criteria for the alternative(s) in Sections 2 and 3 of this guide;
2. Individually, or in combination with other proposed activities, not exceed the thresholds found in Section 40B-4.3010(1), F.A.C.;
3. Not include any other activities that require an engineer according to section 40B-4.3010(3), F.A.C.;
4. Be provided on a construction drawing providing a plan and profile view of the project, construction details for the hardened portion of the project, and a description of how the alternative will transition to adjacent properties/natural conditions;
5. Qualify for a letter of consent for work in, on or over Submerged State Lands;
6. Qualify for an Environmental Resource Permit type that does not require an engineer;
7. Propose and construct erosion and sedimentation control BMPs landward and waterward of the proposed project;
8. Provide that all disturbed areas for the construction of the project to be vegetated;
9. Plant all vegetation shall be installed within one week of the hardened bank construction; and
10. Have a proposed end date that is within three months of the start date.

A registered Professional Engineer must design the selected alternative if any one of Items above is not met. When an engineer is required, they must also be designated as an agent for the landowner and provide all application information required in Rule 40B-4.3020, F.A.C., for a general WOD permit. District regulatory staff will not recommend alternatives or modifications to a landowner or their engineer. The engineer's design must prevent or mitigate negative impacts to the riverbank and adjacent shoreline, and the construction contractor must ensure that project installation has minimal impacts to the environment and adjacent landowners.

## 3.1 Rip Rap with Vegetation

Rip rap is a popular shoreline stabilization alternative consisting of loose stone or clean concrete rubble placed together to ensure interlocking for increased stability while loose enough to allow seeding or planting as described in Section 2.1. Rip rap can be used to stabilize flat to moderate shorelines and riverbanks to reduce erosion and scour, and should not be used for steep to vertical slopes.

Rip rap revetments with vegetation are not typically designed to reduce flow velocity or absorb energy along the bank. For this alternative, larger stone sizes should be used and placed at a minimum thickness (or cross-section depth) to reduce the probability of erosion and allow vegetative growth. Rock sizing may be determined based on-site conditions, such as boat wakes, current flow velocity, and expected upland stormwater runoff. Generally, stones are placed along a slope no steeper than 1.25H:1V. Concrete may be used to hold the rip rap together but should not completely cover the bank. Additional rip rap may be required at the toe of the slope.

The rip rap installation process requires clearing the project area of any debris, rocks, roots, and invasive plants. Typically, machinery is used to place the stones over the slope of the shoreline. Prior to rock placement, a geotextile filter fabric placed on the ground surface is used as a base to stabilize the soil beneath and allow for drainage. Seeding of vegetation should also occur prior to placement of the rip rap, while planting may occur during or after installation. Proper BMPs are required to be used and maintained during all stages of the work. Careful placement of the rip rap must be exercised so as not to puncture or rip the geotextile filter fabric. Displacement of individual stones should be expected, particularly under storm or flood events. Periodic maintenance, replacement, and redistribution of the stones may be necessary to maintain stone interlocking and structural integrity of the system. Maintenance or replacement of vegetation may be required until the vegetation matures.

**Table 3.1** Rip Rap Design Criteria

| **Site Characteristics** | Gentle to Moderate Slopes |
|---|---|
| **Avg. Estimated Service Life** | 20 years |
| **Approx. Installed Cost to Cover 10 ft. in Width (assuming avg. 1.5 ft. diameter rocks/ not including vegetation or backfill)** | \$100/LF (source: Marine Contracting Group, Inc.)<br>\$10,000/100 FT |

**Figure 3.1** Rip Rap and Vegetation Hybrid Shoreline Example

## 3.2 Reinforced Vegetated Slope Terrace

A reinforced vegetated slope terrace is a system of horizontal layers of compacted soil wrapped in a synthetic geotextile fabric to create a stepped feature along the sloped shoreline. This system is designed to be used in combination with native planting as described in Section 2.1. A reinforced vegetated sloped terrace should only be applied to slopes above the OHWL. However, the alternative could be applied below the OHWL with engineering to secure the terrace and proper site preparation, such as rip rap or other alternatives. The terraced area reinforces the riverbank slope, trapping sediment carried by upland runoff, while potentially improving water quality for surrounding receiving waters. The vegetated terraced feature provides support for terrestrial, riparian, and aquatic habitats that enhance the shoreline aesthetics. Vegetation can be planted or staked between soil layers to enhance growth and secure root systems.

Reinforced vegetated slope terracing consists of a woven or non-woven fabric (depending on site and soil conditions) coupled with a geosynthetic grid reinforcement mat for increased strength and durability. The fabric is manufactured in large rolls of varying lengths and should be installed on flat to moderate slopes after clearing the project area of any debris, rocks, roots and invasive plants. The stepped-face terrace installation requires the use of machinery and intense labor during low flow conditions. The fabric should be placed on a flat level ground surface. Clean sand or soil fill is placed on the fabric in lifts and the soil is moderately compacted to achieve the design step height. The fabric is folded over the fill towards the bank and secured with fill such that the waterward face of the step is fully wrapped by the fabric/grid system. The next layer is stepped back/landward in accordance with manufacturers recommendations based on site characteristics. This process is repeated for the next terrace until the upper most level is completed. Following installation, periodic visual monitoring of the system is recommended until vegetation is well established to ensure stepped feature remains intact.

**Table 3.2** Reinforced Vegetated Slope Terrace Design Criteria

| | |
|---|---|
| **Site Characteristics** | Moderate to Steep Slopes |
| **Avg. Estimated Service Life** | 10 to 15 years |
| **Approximate Installed Cost to Cover 10 ft. in Width (not including backfill or vegetation)** | \$180/LF (source: RH Moore & Assoc., Inc.)<br>\$18,000/100 FT |

**Figure 3.2** Example of Reinforced Vegetated Slope Terrace (source: Tensar)

### 3.3 Hybrid Concrete Geogrid Slope Reinforcement

The hybrid concrete geogrid slope reinforcement is composed of individual concrete blocks bonded with a geogrid mat or joined by flexible steel bars. This system is intended for use in combination with seeding or planting as described in Section 2.1. Vegetation can be established over the product by seeding or sodding the open surfaces, which accounts for roughly 30% of the surface area. The hybrid mats are prefabricated and typically available in 4-, 8-, or 10-foot widths with various customizable lengths. Installation requires machinery and a large work area, even to install the smaller mats. For increased performance against shoreline erosion, this product should be applied over larger stretches of shoreline and extend waterward of the OHWL with adequate toe stabilization. When waterward installation is not feasible, the toe of the mats can be anchored using manufacturer-recommended anchors.

The installation process requires clearing the project area of any debris, rocks, roots and invasive plants; and grading and compacting the slope to prepare the application area. A geotextile fabric is placed on the land surface and anchored. The geogrid is then placed over the geotextile fabric, extending part of the concrete mat underwater. The top and toe of the slope must be anchored using a rip rap and the perimeter along either end should be secured to the contiguous mat sections using the manufacturer-recommended anchors. These systems require periodic monitoring and maintenance to ensure that anchors remain in place and that vegetation matures and takes root for increased stability.

**Table 3.3** Hybrid Concrete Geogrid Slope Reinforcement Design Criteria

| **Site Characteristics** | Moderate to Steep Slopes |
|---|---|
| **Avg. Estimated Service Life** | 10 to 15 years |
| **Approx. Installed Cost to Cover 10 ft. in Width (not including vegetation)** | $75/LF (source: RH Moore & Assoc., Inc.)<br>$7,500/100 FT |

**Figure 3.3** Example of Hybrid Concrete Geogrid Slope Reinforcement (source: GeoSolutions)

### 3.4 Marine Mattress

Marine mattresses are modular, stone-filled, flexible, rectangular baskets made of synthetic material that is designed to be used in combination with seeding or planting as described in Section 2.1. The flexibility of the material allows the mattresses to conform to land contours and irregular subgrade conditions. The baskets are manufactured using a high-strength UV-stabilized polypropylene grid material that is resistant to chemical and biological degradation. The marine mattress compartments are typically filled with stone ranging from four to eight inches in diameter. Common marine mattress applications include shoreline erosion control as well as foundations for pipelines and breakwaters, dune stabilization, and bridge scour protection. Due to the encased and interlocking matrix of stones, marine mattresses are designed to withstand somewhat higher flow velocities than smaller loose stone rip rap revetments. These systems can also act as energy dissipators. Mattress sizes are typically five feet in width, available in 6- to 24-inch thicknesses, and can be customized for lengths up to 30 feet.

The marine mattresses installation process requires clearing the project area of any debris, rocks, roots, and invasive plants. Installation requires heavy machinery and a large work area. A geotextile fabric is typically placed underneath the mattress to reduce settlement and soil loss. The mattress can be pre-filled upon delivery or filled on site after placement of the empty baskets. The basket openings are joined together using a high-strength braided cord. For steeper slope applications, the use of U-shaped anchors, such as 24-inch-long steel rods, are recommended to secure the mats to the riverbank. The polypropylene grid material can be susceptible to degradation from UV exposure for extended periods of time, lasting between six months to two years on average. These systems require periodic monitoring and maintenance to ensure that anchors remain in place and that vegetation matures and takes root for increased stability.

**Table 3.4** Marine Mattress Design Criteria

| | |
|---|---|
| **Site Characteristics** | Moderate to Steep Slopes |
| **Avg. Estimated Service Life** | 20 years |
| **Approximate Installed Cost to Cover 10 ft. in Width (not including vegetation)** | \$175/LF (source: USACE)<br>\$17,500/100 FT |

**Figure 3.4** Example of Marine Mattress System (source: Tensar)

### 3.5 Open-Celled Articulated Concrete Blocks

Articulated concrete blocks (ACBs) consist of a matrix of individual concrete blocks connected with high-strength flexible steel or polyester cables. The concrete blocks are designed with interlocking flanges that are intended to resist strong hydraulic loading conditions. The open-celled blocks have voids that allow native seeding or planting as described in Section 2.1. The ACBs are available in varying sizes but usually come in eight-feet-width prefabricated mats of different lengths. The product also comes in individual block units, intended for filling in voids or gaps between ACB sections.

The installation process requires clearing the project area of any debris, rocks, roots and invasive plants, and grading and compacting the slope to prepare the application area. A geotextile fabric is typically installed prior to placement of the ACBs to provide drainage beneath the blocks and allow vegetation growth. The ACBs can be used for moderate to steep slopes, up to 1H:1V. The ACBs are typically placed using heavy machinery and a spreader bar perpendicular to the shoreline. The top and toe of the concrete block mattress system must be secured using an anchor trench in accordance with manufacturers recommendations. Adjacent concrete block mattress sections are secured together using U-shaped steel anchoring rods. Following installation of the ACB mattress, the open cells within each block can be seeded or planted to promote vegetative growth as described in Section 2.1. These systems require periodic monitoring and maintenance to ensure that anchors remain in place and that vegetation matures and takes root for increased stability.

**Table 3.5** Open-Celled Articulated Concrete Block Mattress Design Criteria

| | |
|---|---|
| **Site Characteristics** | Moderate to Steep Slopes |
| **Service Life** | 20 years |
| **Approx. Installed Cost to Cover 10 ft. in Width (not including vegetation)** | \$125/LF (source: RH Moore & Assoc., Inc.)<br>\$12,500/100 FT |

**Figure 3.5** Example of Open-Celled Articulated Concrete Blocks (source: Shoretec)

## 4.0 HARDENED ENGINEERED ALTERNATIVES WITHOUT VEGETATION

The alternatives in this section are permanent and all require design by a Florida registered Professional Engineer and construction by a Florida licensed general contractor. The alternatives are structural and do not have voids large enough to support vegetation; therefore, they must control the hydrodynamic and hydrostatic pressures from the soils behind the structure and from the river. These alternatives allow for construction waterward of the existing bank and require a more substantial permitting process than non-engineered or hybrid shoreline erosion control alternatives. Often, additional permits such as an ERP, SSL authorization, and USACE authorization will be required. Vegetation seeding or re-planting is required in all areas disturbed during the construction, even if not included as part of the proposed project.

The alternatives described below, detail each alternative's advantages as well as the range of suitable slopes, approximate design service life, installation techniques, and estimated installation costs. The material and installation costs were estimated using manufacturer quotes. Material and installation costs are subject to change and may vary based on availability, site location, accessibility, and general site conditions. Actual service life may differ due to site conditions, frequency and intensity of storm events, availability of materials, project logistics, construction quality control, and post-construction maintenance. Site conditions will dictate which alternative(s) are appropriate for each property as well as the dimensions. Costs shown in the alternatives below include neither the design or permitting costs nor the costs of installing erosion and sedimentation BMPs.

### 4.1 Rip Rap Revetment

The use of rip rap is a popular shoreline stabilization alternative consisting of loose stone or clean concrete rubble placed tightly together to ensure interlocking for increased stability. Rip rap revetments can be constructed in a wide range of sizes and configurations to provide long-term shoreline stabilization. Rip rap revetments are typically designed to reduce flow velocity and absorb energy along an embankment. Typically riprap stones range from 9 to 24 inches in diameter and are placed at a minimum thickness (or cross-section depth) of two to three stones. However, rock sizing may be determined based on-site conditions, such as boat wakes, current flow velocity, and expected upland stormwater runoff. Generally, stones are placed along a slope no steeper than 1H:1V. Concrete may be used to bond the stone. Special consideration should be used at the top of the revetment to address stormwater runoff and stone displacement.

Rip rap revetment installation typically requires the use of a front-end loader to place the stones over the slope of a shoreline. Prior to rock placement, a geotextile filter fabric is used as a base on land surface to stabilize the underlying soil and allow for drainage. Proper BMPs are required to be used and maintained during all stages of the work. Displacement of individual stones should be expected particularly during storm or flood events. Periodic maintenance, replacement, and redistribution of the stones may be necessary to maintain stone interlocking and structural integrity of the system.

**Table 4.1** Rip Rap Design Criteria

| **Site Characteristics** | Gentle to Moderate Slopes |
|---|---|
| **Avg. Estimated Service Life** | 20 years |
| **Approx. Installed Cost to Cover 10 ft. in Width (assuming 1.5 ft. diameter rocks)** | \$100/LF (source: Marine Contracting Group, Inc.)<br>\$10,000/100 FT |

**Figure 4.1** Example of Rip Rap

### 4.2 Closed-Cell Articulated Concrete Blocks

This alternative consists of a matrix of individual concrete blocks connected with high-strength flexible steel or polyester cables. The concrete blocks are designed with interlocking flanges and are available in varying sizes. The interlocking design resists strong hydraulic loading conditions. The closed-celled blocks do not have voids allowing vegetation growth. Articulated concrete blocks present a durable, low-maintenance shoreline erosion control method. The blocks are typically manufactured as individual or eight-feet width prefabricated mats in various lengths connected by corrosion-resistant steel cables or polyester material.

Similar to the hybrid concrete geogrid and marine mattresses, a geotextile fabric is typically installed prior to placement of the concrete block mattress. The individual block units work for moderate slopes, but the prefabricated mat is recommended for steep slopes up to a maximum of 1H:1V. The installation process requires clearing the project area of any debris, rocks, roots, and invasive plants, to ensure a level surface. The articulate concrete blocks are typically placed using heavy machinery. The top and toe of the concrete block mattress system must be secured using an anchor trench in accordance with manufacturer recommendations. Adjacent concrete block mattress sections are secured together using U-shaped steel anchoring rods.

**Table 4.2** Closed-Cell Articulate Concrete Blocks Mattress Design Criteria

| **Site Characteristics** | Moderate to Steep Slopes |
|---|---|
| **Avg. Estimated Service Life** | 20 years |
| **Approx. Installed Cost to Cover 10 ft. in Width (not including backfill)** | $125/LF (source: RH Moore & Assoc., Inc.)<br>$12,500/100 FT |

**Figure 4.2** Example of Closed-Cell Articulated Concrete Blocks (source: Shoretec)

### 4.3 Gabions

Gabions are rectangular wire mesh baskets commonly filled with small stones ranging from two to eight inches in diameter to create a gravity structure. The baskets come in varying sizes and are stacked to create low-cost retaining walls for moderate to steep slopes, but not vertical slopes. Gabions are manufactured using a double twist wire mesh, that provides strength, durability, and flexibility to adapt to slope settlement/displacement. The steel mesh basket wire has a PVC coating to prevent corrosion and extend the service life. The primary advantages of gabions include low maintenance, durability, and the capability for surface and groundwater drainage through the face to reduce hydrostatic pressure from behind the system. Gabions can be installed from nearly vertical to a terraced (stepped) configuration, providing a “bench” for vegetative plantings. The existing site conditions will dictate the engineering design and ultimate configuration.

Prior to basket installation, the project area must be cleared of any debris, rocks, roots, and invasive plants. The placement area must be level and compacted with a geotextile fabric placed on the slope to minimize the scour risk in accordance with the engineered plans. Generally, the first row of baskets is placed at the toe with each basket unit connected to one another. Once in place, the baskets are filled with small stones by hand or machinery. The stone fill must be rodded prior to closure to ensure tight interlocking within each cellular basket. The gabion rows are typically stepped slightly landward for increased structural stability; however, the depth of the setback shall be designed by the engineer. Once installed, the slope is backfilled, compacted, and vegetated. Periodic maintenance and monitoring are recommended to identify potential damage to the wire mesh and signs of settlement. Settlement of the gabion system may result in basket breakage and structural failure in some sections.

**Table 4.3** Gabions Design Criteria

| **Site Characteristics** | Moderate to Steep Slopes |
|---|---|
| **Avg. Estimated Service Life** | 15 to 30 years |
| **Approx. Installed Cost for 3 Gabion Rows (9 ft. tall structure/ not including backfill)** | \$250/LF (source: Marine Contracting Group, Inc.) \$25,000/100 FT |

**Figure 4.3** Example of Gabions

### 4.4 Bulkheads

Bulkheads are vertical walls that separate water from land to control shoreline erosion. Bulkheads can be constructed using a range of materials including concrete, timber, vinyl, or a plastic fiber reinforced composite. While timber is typically the most cost-effective option, it is only recommended for freshwater applications. Concrete, vinyl and plastic fiber reinforced composite walls generally provide a much longer service life under the same conditions. The cost for each alternative varies greatly depending on the material selected, site conditions, equipment access, and installation technique.

Bulkheads can be used to stabilize shorelines with moderate to vertical slopes and are designed to perform and maintain stability during storms and high flood events. A typical bulkhead design requires an anchor system landward of the wall to support lateral loads, rip rap to protect the structure toe from scouring, and a cap to reinforce and stabilize the walls and control overland flow. Bulkhead designs also require proper tie-ins at each end (upstream and downstream) of the bulkhead terminus to secure the bulkhead and minimize adverse effects to adjacent neighboring properties and shorelines. Bulkhead construction requires specialized equipment and an experienced contractor. Some excavation may be needed for proper installation. Consultation with a licensed contractor and Professional Engineer is recommended for construction material selection and design for the particular site conditions. The design will also be influenced by the height of the eroded shoreline slope and site access. Therefore, material costs will vary depending on bulkhead length, height, and wall thickness. Maintenance costs are typically low with maintenance usually only required at the toe, top, or ends of the wall.

**Table 4.4** Timber Bulkheads Design Criteria

| | |
|---|---|
| **Site Characteristics** | Moderate to Steep Slopes |
| **Avg. Estimated Service Life** | 25 years |
| **Approx. Installed Cost for an 8-ft Panel Length (not including toe rock or backfill)** | $400/LF<br>$40,000/100 FT |

**Figure 4.4** Example of Timber Bulkhead

## 5.0 SUMMARY AND RECOMENDATIONS

The *Homeowners' Shoreline Erosion Control Guide* describes a range of alternatives that property owners might consider to stabilize eroding shorelines along WOD rivers. The alternatives in each section were evaluated based on the typical slopes and site conditions present along river floodways. Landowners should examine the conditions and characteristics of their property and consider the important parameters outlined in Section 1.1 when evaluating the stabilization alternatives outlined herein. In addition, other factors such as available upland space, construction and equipment access, drainage considerations, and installation requirements must be considered in order to result in a successful project. A permit as well as a pre-application meeting is required prior to implementation of any of the alternatives presented in this guide. Tables 5.1 through 5.3 provide a brief comparative matrix of the alternatives described within each section of this guide. For additional information, please contact District regulatory staff by email at resourcemanagement@srwmd.org or call 386.362.1001.

**Table 5.1** Summary of Soft Stabilization Alternatives with Vegetation

| | Native Vegetation Planting | Coir Logs | Erosion Control Blankets | Reinforcement Mats | Geogrid Mat |
|---|---|---|---|---|---|
| **Site Characteristics** | Gentle to Moderate Slopes | Gentle to Moderate Slopes | Gentle to Moderate Slopes | Moderate to Steep Slopes | Moderate to Steep Slopes |
| **Service Life (Years)** | 5 | 2 to 5 | 2 | 10 | 10 |
| **Approximate Installed Cost ($/LF) ($100 FT)** | 10<br>1,000 | 20<br>2,000 | 8<br>800 | 25<br>2,500 | 25<br>2,500 |

**Table 5.2** Summary of Hybrid Shoreline Stabilization Alternatives

| | Rip Rap with Vegetation | Reinforced Vegetated Slope Terrace | Hybrid Concrete Geogrid Slope Reinforcement | Marine Mattress | Open-Celled Articulated Concrete Blocks |
|---|---|---|---|---|---|
| **Site Characteristics** | Gentle to Moderate Slopes | Moderate to Steep Slopes | Moderate to Steep Slopes | Moderate to Steep Slopes | Moderate to Steep Slopes |
| **Service Life (Years)** | 20 | 10 to 15 | 20 | 20 | 20 |
| **Approximate Installed Cost ($/LF) ($100 FT)** | 100<br>10,000 | 180<br>18,000 | 75<br>7,500 | 175<br>17,500 | 125<br>12,500 |

**Table 5.3** Summary of Hard Stabilization Alternatives

| | Rip Rap Revetment | Closed-Cell Articulated Concrete Blocks | Gabions | Timber Bulkheads |
|---|---|---|---|---|
| **Site Characteristics** | Gentle to Moderate Slopes | Moderate to Steep Slopes | Moderate to Steep Slopes | Moderate to Steep Slopes |
| **Service Life (Years)** | 20 | 20 | 15 to 30 | 25 |
| **Approximate Installed Cost ($/LF) ($100 FT)** | 100<br>10,000 | 125<br>12,500 | 250<br>25,000 | 400<br>40,000 |

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