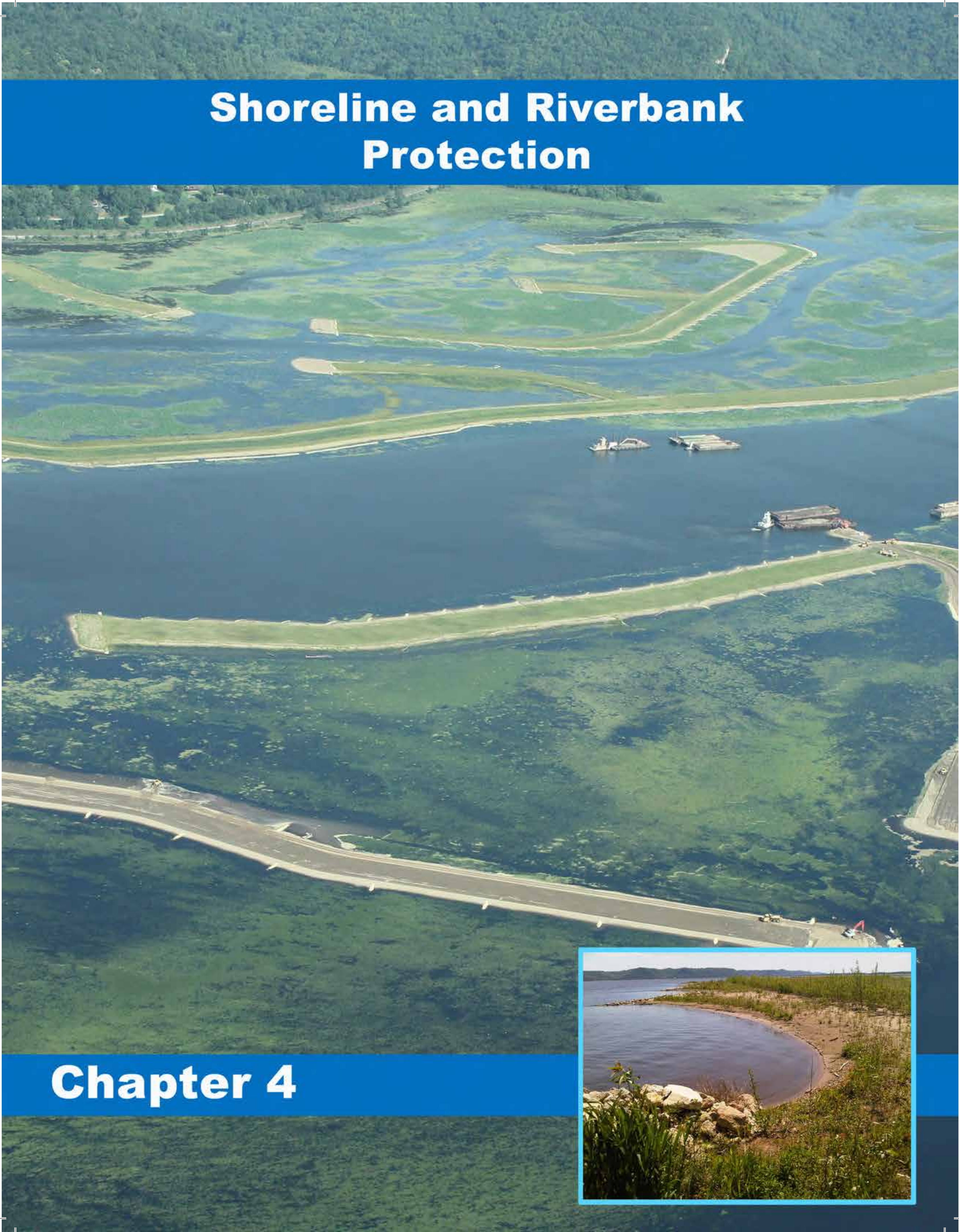
Shoreline and Riverbank Protection

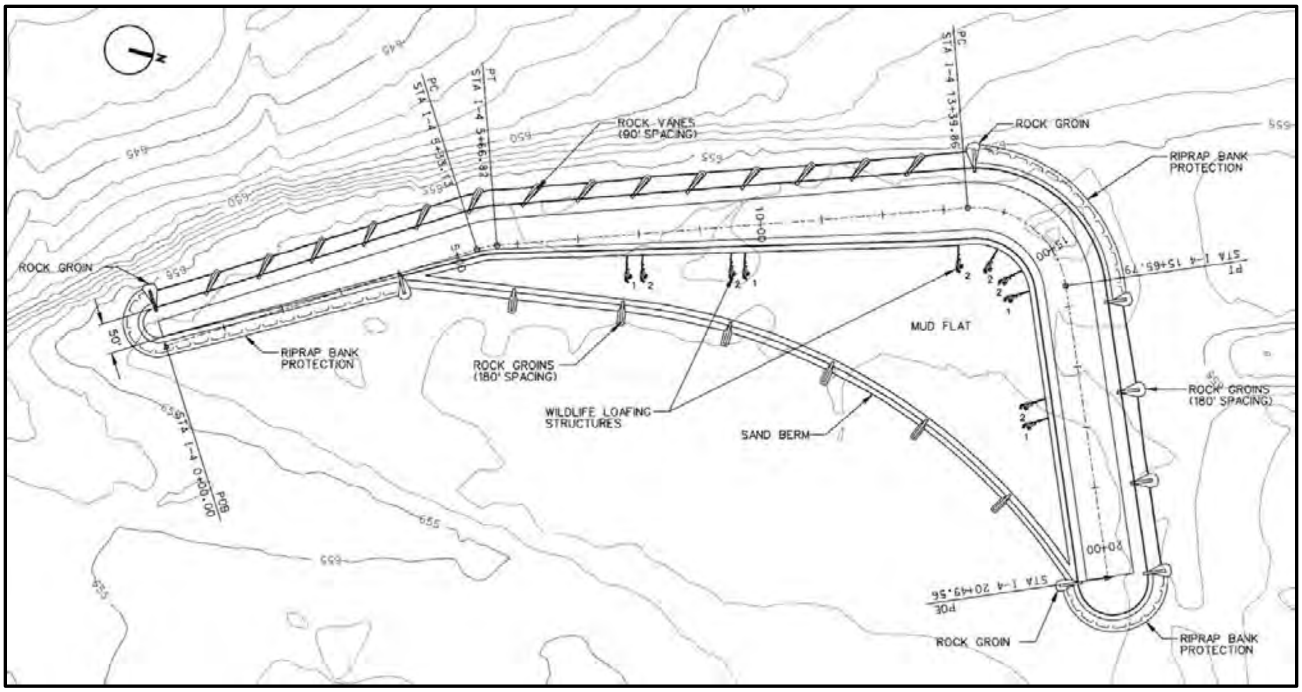


Chapter 4

UPPER MISSISSIPPI RIVER RESTORATION
ENVIRONMENTAL MANAGEMENT PROGRAM
ENVIRONMENTAL DESIGN HANDBOOK

CHAPTER 4

SHORELINE AND RIVER BANK PROTECTION



Point of Contact for Chapter 4
Kari L. Hauck, P.E.
U.S. Army Corps of Engineers, St. Paul District
CEMVP-EC-H
180 Fifth Street East, Suite 700
St. Paul, MN 55101-1678
Kari.L.Hauck@usace.army.mil
651-290-5424

UPPER MISSISSIPPI RIVER RESTORATION
ENVIRONMENTAL MANAGEMENT PROGRAM
ENVIRONMENTAL DESIGN HANDBOOK

CHAPTER 4

SHORELINE AND RIVER BANK PROTECTION

CASE STUDIES

PHOTOGRAPHS

TABLES

FIGURES

UPPER MISSISSIPPI RIVER RESTORATION
ENVIRONMENTAL MANAGEMENT PROGRAM
ENVIRONMENTAL DESIGN HANDBOOK

CHAPTER 4

SHORELINE AND RIVER BANK PROTECTION

A. RESOURCE PROBLEMS AND OPPORTUNITIES

After the locks and dams were constructed in the 1930s, shoreline erosion increased due to exposure to erosive forces from wind driven wave action, river currents, and ice action. As islands eroded in the lower reaches of navigation pools, the amount of open water increased and the magnitude of the erosive forces increased. This was exacerbated by the loss of aquatic vegetation, which created even more open water. As this occurred, more shoreline was exposed and gave way to the erosive forces. This chapter provides methods for mitigating erosion of natural and newly constructed shoreline on the Upper Mississippi River.

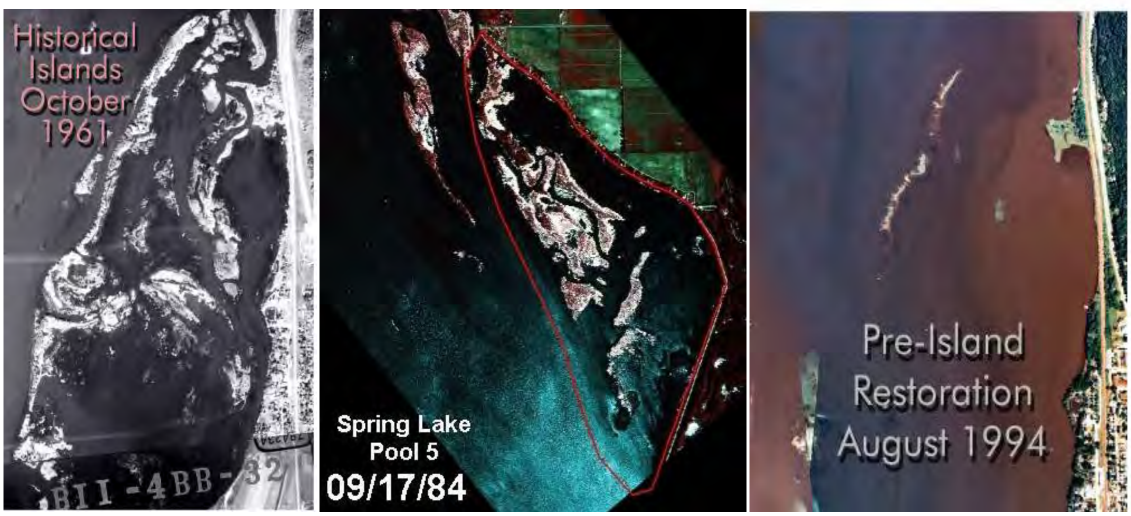
1. Pre-Inundation Conditions. The Upper Mississippi River is island braided with many anatomizing side channels, sloughs, backwaters, and islands (Collins & Knox, 2003). Natural levees separate the channels from the backwaters and floodplain. In its natural state, the flow of water and sediment was confined to channels during low flow conditions. For larger floods, the natural levees were submerged resulting in water and sediment conveyance in the floodplain, however channel conveyance continued to be high since floodplain vegetation increased resistance and reduced discharge in the floodplain. Geomorphic processes such as erosion, deposition, and channel migration was a natural process occurring at variable rates depending on river slope, floodplain size, geomorphic controls like tributaries or rapids, and sediment loads. By the 1930s, these geomorphic processes were significantly changed by the earlier attempts to establish a 4 ½ and later a 6 foot navigation channel. Training structures consisting of wing dams, closing dams, and bank revetments; along with dredge material placement was used to narrow and deepen the main channel of the river for navigation. Conversion of tributary watersheds to agriculture combined with the extremely poor practice of logging on hillside slopes resulted in elevated sediment loads in the tributaries, causing significant deposition in tributary floodplains, and in some instances increased sediment fluxes to the Mississippi River. Deforestation along the river to fuel steamboats in the 1800s and then later for agricultural and urban development, changed the riparian and floodplain areas significantly. Agricultural levee districts sequestered large areas of the floodplain from the river in south of Rock Island. All of these changes had some effect, in some cases de-stabilizing river banks, and in other cases actually stabilizing them. Some of these effects may have been masked by the fact that river discharges had been decreasing between 1880 and 1930.

2. Resource Problems. The river today is a reflection of many changes that have altered its natural condition (Chen & Simons, 1979, Collins & Knox, 2003). These include the early attempts to use the river for navigation and convert the watershed to agriculture, along with the urbanization of some reaches of the river, the introduction of aquatic nuisance species, and climate variation which has caused a trend of increased river discharges beginning in the 1930s and continuing to the present. In the impounded reaches of the river above St. Louis, Missouri, the construction of the Locks and Dams in the 1930s is the most significant event affecting shoreline and river bank stability and the condition of the river today.

Construction of the locks and dams submerged portions of the natural levees and floodplain creating navigation pools upstream of the dams and leaving only the higher parts of the natural levees as islands. The physical changes created by lock and dam construction produced a significant biological response in the lower reaches of the navigation pools. The original floodplain, which consisted of floodplain forests, shrub carrs, wetlands, and potholes, was converted into a large permanently submerged aquatic system. These areas are commonly called backwaters. A diverse assemblage of aquatic plants colonized the backwaters, with the distribution of plant species being a function of water depth, current velocity, and water quality. Fish and wildlife flourished in this artificial environment for several decades after submergence, however sediment deposition, permanent submergence, and shoreline erosion caused a gradual decline in the habitat that had been created in the backwaters.

In the navigation pools, shoreline erosion increased after lock and dam construction permanently raised water levels over the long term killed riparian trees. Tree uprooting in later years destabilized some river banks. Wave action and river currents are constantly acting on alluvial soils, previously in the riparian zone, that had only been subject to these forces during seasonal high water and were partly sheltered because of their location.

Wind fetch was immediately increased when the floodplain was inundated, and continued to increase as features in the lower halves of navigation pools disappeared. This process is shown in photograph 1.



Photograph 4-1. Degradation at Spring Lake, Pool 5

The transport of sediment was altered resulting in sediment deposition in the middle reaches of navigation pools, and reduced sediment loads to the lower reaches, which may have contributed to shoreline erosion.

3. Resource Opportunities. The increase in shoreline erosion is directly linked to the changes that have been made to the river as described in the previous section. In the lower reaches of navigation pools, this was exacerbated by the loss of natural islands and structure in the river through erosion. This structure is necessary to achieve the diversity in water depths, current velocities, and water quality desirable in channels and backwater areas.

Shoreline stabilization is used on new HREPs such as island shorelines or water level management projects and it is also used to stabilize existing shorelines that might be eroding. In areas where the natural structure has been lost, island construction can reverse or alter the impacts created by the locks and dams. On new projects, it is an added expense that is justified because of the investments made in the project. On existing shorelines, stabilization usually can only be justified if additional habitat besides the shoreline itself will be enhanced or preserved.

4. HREP Objectives. HREP features are designed with the intent of meeting specific project objectives. It is important for the design team to have an understanding of the relationship between project features and objectives to help maximum benefits and minimize costs. Also, many of the effects of these features occur secondarily to the obvious primary effects; understanding these relationships even at a basic level can help inform design decisions.

Table 3-1 in Chapter 3 of this Handbook shows many examples of non-specific objectives for HREPs categorized by Essential Ecosystem Characteristics. For actual projects, these objectives would be more focused, but they are useful here to help provide a basic understanding of how project features can be used to meet multiple objectives. Following is a discussion of each category, some of the objectives that can be addressed through shoreline protection features and their relationships are briefly discussed. It should be noted that this is not an all-inclusive list, but is being used here to facilitate consideration of the numerous relationships between features and objectives.

a. Hydraulics and Hydrology: Shoreline protection features generally do not directly affect hydrology, but their primary purpose is to modify hydraulics at the substrate/water interface to prevent erosion. By preventing erosion, shoreline protection features are used to maintain islands, which are often created or protected in order to support a certain level of lateral hydraulic connectivity (often maintaining a reduced level of lateral connectivity), often an important objective in HREPs.

b. Geomorphology: Shoreline protection features directly affect geomorphology. They contribute to maintaining topographic and bathymetric diversity objectives by helping to prevent erosion of high areas and, consequently, the sedimentation of deeper areas. They also contribute to maintaining flow and sediment transportation rates in side channels by assuring the existence of land masses that direct flows. When these features are used to maintain a relative lack of lateral connectivity by protecting barrier islands, they help reduce sedimentation in backwaters and, therefore, help meet bathymetric diversity objectives there. Features such as groins and vanes contribute directly to bathymetric diversity objectives in their immediate vicinities by their construction and the subsequent creation of scour holes in certain cases.

c. Biogeochemistry: Shoreline protection features indirectly affect biogeochemistry in many ways. Reducing suspended sediment loads by preventing erosion and directing the flow of sediment-laden water can reduce sediment and contaminant loading and improve water clarity, especially in backwaters. Increasing water clarity improves vegetation growth, which can affect nutrient processing and dissolved oxygen levels. Nutrient processing and dissolved oxygen are also affected by water exchange rates, which are controlled by lateral connectivity.

d. Habitat: Shoreline protection features affect habitat directly and indirectly, and these effects result from changes to the previous three categories discussed above. Shoreline protection features prevent the erosion and loss of terrestrial and riparian habitat such as bottomland forest. They also ensure the maintenance of similar created habitats such as islands. Because they prevent the loss of these habitats, they support aquatic habitat objectives that would be addressed by these features, especially those related to lateral connectivity.

The rock used in the construction of these features provides habitat for aquatic invertebrates and fish, but it can also create a hazard and a barrier for turtles and other riparian wildlife. The use of vegetation in stabilizing banks where appropriate can provide better riparian habitat, but groins and vanes are less intrusive than riprap may be a preferred compromise. Offshore rock mounds used to protect banks provide relatively unique protected wetland habitat between the mound and shoreline.

e. Biota: Shoreline protection features (and most features used in HREPs) indirectly affect biota through other effects to hydrology, geomorphology, biogeochemistry, and habitat. The effects to biota are seldom measurable in a manner that can clearly prove a cause and effect relationship with project features, so they are often assumed to correlate with physical habitat objectives.

B. MANAGEMENT ACTION

The primary forces that affect shorelines are river currents and wind driven wave action, though ice action and waves created by towboats or recreational boats can also cause erosion. The following techniques are used to mitigate the erosive forces and are further described in table 4-1:

- Riprap (Photograph 4-2)
- Bio-Geo methods (Photographs 4-3 and 4-4)
- Vegetative stabilization (Photograph 4-5)

These techniques can be employed singly or in combination to protect shoreline and add habitat diversity to the system. For example, more gradual side slopes and sand or mud soils can be beneficial to turtles, and waterbirds that nest, feed, and loaf on the shorelines. Native plantings are more aesthetically pleasing than traditional bank stabilization (i.e., riprap). Traditional stabilization techniques are also being reviewed to improve habitat benefits. Larger rock and mixed grade rock can create greater fish and invertebrate habitat diversity by providing bigger crevices for shelter and flow diversity (Report to Congress, 2004).

Photograph 4-2. Riprap and Geotextile Filter Placed on Sand (Lake Onalaska)

Photograph 4.3. Bio-Geo Stabilization with Groins and Willows (Boomerang Island)

Photograph 4-4. Vanes

Photograph 4-5. Vegetative Stabilization (Boomerang Island)

Table 4-1. Description of Shoreline Stabilization Techniques

Stabilization Technique	When To Use	Description	Advantages	Disadvantages
Rock Fill (no filter)	Remote site where erosive action is severe. If off-shore depths are greater than 5 ft deep, or if feature being protected has a convex shape in plan, rockfill should be considered. If ice action will occur, rock fill may be the best choice because of self-healing properties.	Rock fill increases the shear strength of the shoreline so that erosive forces do not displace shoreline substrate. The thickness and size of the riprap varies depending on the magnitude of the erosive force. Rock fill thickness is increased over the thickness of riprap so the layer is self-filtering. A 24-" layer is used in most situations.	Rock fill can be designed and placed so that a continuous thick layer of rock results. Its performance and cost can be predicted more reliably than some other methods, and because of the greater thickness, it has self healing properties in the event of ice action or toe scour.	Cost is relatively high (see figure 4-4) because stabilization relies on continuous coverage of the shoreline with rock. Creates an unnatural aquatic/terrestrial transition which may not be beneficial to some species.
Riprap w/ Filter	Easily accessible site with severe erosive action. If off-shore depths are greater than 5 ft, or if feature being protected has a convex shape in plan, rockfill should be considered.	Riprap increases the shear strength of the shoreline so that erosive forces do not displace shoreline substrate. The thickness and size of the riprap varies depending on the magnitude of the erosive force. Because riprap layer thickness is less than rock fill, a granular or geotextile filter is required to prevent loss of su4-grade material	Less volume of rock used so if cost per linear foot of filter is less than additional rock in a rock fill layer it is less expensive than rock fill with no filter.	Creates an unnatural aquatic/terrestrial transition which may not be beneficial to some species. If site is remote, transporting the filter material to the site may be difficult which adds to the cost.
Groins	Where erosive action is mainly due to wave action and off-shore depths are less than 3 ft at the end of the groin. Shoreline material type should consist primarily of sand-size material.	Long, narrow rock structures placed perpendicular to shorelines to contain littoral drift (i.e. the transport of sand along a shoreline due to wave action). This results in a scalloped shoreline shape (requiring a sacrificial berm), which is the shoreline adjustment to the prevailing winds. Used in conjunction with planted shoreline vegetation.	One of the lowest cost stabilization techniques. Does have a beach between groins, which is beneficial to some species. More natural looking	Vulnerable to ice action. Needs room for a sacrificial berm consisting of granular fill.
Vanes	Where erosive action is mainly due to river currents. Shoreline material type should consist primarily of sand-size material.	Long, narrow rock structures placed at an upstream angle to shorelines to redirect river currents away from the shoreline. Erosive secondary currents are moved away from the toe of the bank. Used in conjunction with planted shoreline vegetation.	One of the lowest cost stabilization techniques. More effective than groins if there are river currents. Retains a beach which is beneficial to some species. More natural looking	Vulnerable to ice action rock displacement by large woody debris. Needs room for a sacrificial berm consisting of granular fill.
Off-Shore Mounds	When off-shore water depths prevent equipment access to the shoreline being protected.	Long, narrow rock structures placed parallel to shorelines some distance off-shore to reduce erosive forces due to wave action, river currents, or ice action	Creates sheltered aquatic area between mound and shoreline.	High cost Cost effective only in shallow water.
Vegetative Stabilization	Vegetative stabilization can be used along shorelines where offshore velocities are less than 3 ft/sec, wind fetch is less than 1/2 mile, ice action and boat wakes are minimal, or where offshore conditions (depth or vegetation) reduce erosive forces.	Vegetative stabilization consists of plantings of woody tree species or seeding herbaceous vegetation. Other types of stabilization structures, such as groins or vanes, are not used.	Lowest cost stabilization technique In addition to stabilization, it creates habitat.	Limited to shorelines where erosive forces are minimal. Requires the vegetation to flourish. If vegetation is attacked by some type of pest and does not thrive, it will not be effective erosion control.

1. Site Identification. Typically, the project design team (PDT) works together to identify and prioritize areas requiring protection. Coordination with the project sponsor or resource agency is very important in evaluating shoreline erosion. For one project in Pool 18, there was no apparent visual bankline erosion during the site visit, however, based on information from the sponsor, a building foundation remnant was located which had once been 50 feet from the shoreline. At the time of the site visit, the foundation was located at the edge of the island. After researching real estate photograph from the 1930 land acquisition, it was apparent that erosion was occurring (photograph 4-6).

Photograph 4-6. Bankline Erosion at Huron Island, Pool 18 (note building foundation)

Other banklines have more apparent erosion that can be observed during site visits, such as the location in Pool 20 shown in photograph 4-7.

Photograph 4-7. Bankline Erosion on Long Island Division, Pool 20

Survey of banklines is also important in establishing erosion near proposed future features. For accurate survey to be used in computer modeling software such as Bentley Inroads, survey is required along the bankline of the observed eroded section, and extending some distance (i.e. 50 feet) into the river and some distance (i.e. 20 feet) beyond top of bank. Surveyed sections are required at sufficient frequency (i.e. every 50 feet) to provide an accurate model. While topography surveys such as LiDAR and bathymetry surveys are useful for most calculations, pole surveys more accurately capture the bankline slopes and erosion.

Sedimentation transects also exist for many section of the river. Some of these transects provide information from pre-inundation and within the past 20 years. Depending on the location of these transects, this information may be used to determine if the shoreline is migrating.

In the St. Paul District (MVP), erosion assessments, using the worksheet provided in table 4-2, can be completed in the field or by using maps or photographs.

The scoring method assists the PDT in determining if a site requires shoreline stabilization.

Table 4-2. Erosion Stabilization Assessment Worksheet – Shoreline or River Bank Reach

Factor	Criteria	Score	1	2	3	4	5	6	7	8	9	10
River Currents	0 to 1 fps	0										
	1 to 3 fps	5										
	> 3 fps	10										
Wind Fetch	0 to 0.5 miles	0										
	0.5 to 1 mile	5										
	> 1 mile	10										
Navigation Effects	Minimal	0										
	Surface Waves	5										
	Tow Prop-Wash	20										
Ice Action	No Ice Action	0										
	Possible Ice Action	5										
	Observed Bank Displacement	10										
Shoreline Geometry	Perpendicular to wind axis	0										
	Skewed to wind axis	2										
	Convex shape	5										
Nearshore Depths	0 to 3 feet	0										
	> 3 feet	3										
Nearshore Vegetation	Persistent, Emerged	0										
	Emergents	1										
	Submerged or no vegetation	3										
Bank Conditions	Hard Clay, Gravels, Cobbles	0										
	Dense Vegetation	1										
	Sparse Vegetation	2										
	Sand & Silt	3										
Local Sediment Source	Upstream Sand Source	0										
	No Upstream Sand Source	1										
		Total										

Total Score >18 - Bank Stabilization Needed; Total Score = 12 to 18 - Further Analysis Needed; Total Score < 12 - Bank Stabilization Not Needed

Upstream Reach Descriptions

Reach 1 -

Reach 2 -

Downstream Reach Description

Reach 4 -

Reach 5 -

2. Shoreline Stabilization Technique Selection. Once a site has been identified, the type of shoreline stabilization needs to be determined. There is significant variation from project to project depending on site conditions and project objectives. Additionally, river characteristics vary greatly between the districts. As a result, the approach to shoreline stabilization differs between the MVP and the Rock Island District (MVR). In the MVP, a typical distribution used is 20 percent riprap, 40 percent bio-geo, and 40 percent vegetative. More recent island projects in the MVP tend to have less riprap and use more bio-geo and vegetative stabilization. The MVR tends to use more rock. On existing shorelines, riprap and off-shore mounds are used more often than groins or vanes because one of the objectives for stabilizing an existing shoreline is usually to immediately stop erosion. Since groins and vanes allow some continued re-shaping of the shoreline, they are not often used. Table 4- 3 includes examples of various types of shoreline stabilization used on islands that have been constructed and table 4- 4 presents some general guidance for technique selection.

Table 4-3. Example Shoreline Stabilization Technique Distribution

		Riprap Stabilization Length		**Bio-Geo Stabilization Length**		**Vegetative Stabilization Length**		
Island	**Total Shoreline Length**	**(feet)**	**(%)**	**(feet)**	**(%)**	**(feet)**	**(%)**	**Year**
Weaver Bottoms		2,180	13	5,670	33	9,550	55	1986
Pool 8, Phase II Slingshot I	10,800 ft	600	6	7,520	70	2,680	*25*	1999
Polander Lake, Stage 2 Interior Islands	4,210 ft	120	3	0	0	4,090	97	2000
Long Island (Gardner) Div.	3,765 ft	3,765	100	0	0	0	0	2001
Spring Lake Islands, Island 3	74,000 ft	600	1	44,500	60	2,890	39	2006
Pool 11 Islands Sunfish Lake	4,921 ft	4,921	100					2002
Pool 11 Islands Mud Lake	3,477 ft	3,477	100					2004
Spring Lake	Perimeter Levee		100					1990s

Table 4-4. General Guidance for Stabilization Technique Selection

	Design Considerations							**Habitat Considerations**		
Feature	New Construction	Existing Shoreline	Water Depth < 3 ft	3 ft < Water Depth < 5 ft	Water Depth > 5 ft	Shoreline subject to wave action & littoral drift	Shoreline adjacent to moving current	Provide floodplain habitat & sand for beach formation	Provide habitat and elevation diversity	Provide protected deep waters
Rock Revetment	x	x	x	x	x	x	x			
Rock Groin	x	x	x	x		x				
Rock Vane	x	x	x	x	x		x		x	x
Off shore Rock	x	x	x	x		x	x		x	
Sand Berm	x	x	x	x		x	x	x	x	
Vegetation	x		x			x	x		x	
Large Woody Debris	x		x	x	x	x	x		x	

3. Cost. Shoreline stabilization costs include earth fill (granular and fines) for the berm, rock, and the cost of willow plantings. Figure 4-1 shows estimated costs, based on data collected by the MVP, for constructing various types of rock based shoreline stabilization in water depths of 1 to 6 feet. Based on this information, groins and vanes are the cheapest rock based stabilization option, regardless of water depth. Rock mounds are the most expensive option in all cases.

As is shown in table 4-5, vegetative solutions are the most cost effective method of shoreline stabilization. However, very few eroded sites can rely solely on vegetation for bank stabilization.

Table 4-5. Cost of Willow Plantings on Two Island Projects

Project	Bid Price	Shoreline Length	Cost per Foot	Year
Pool 8, Phase III, Stage 3B	$27,000	10,940	$2.47	2009
Pool 9, Capoli, Stage 1	$53,081	16,070	$3.30	2011

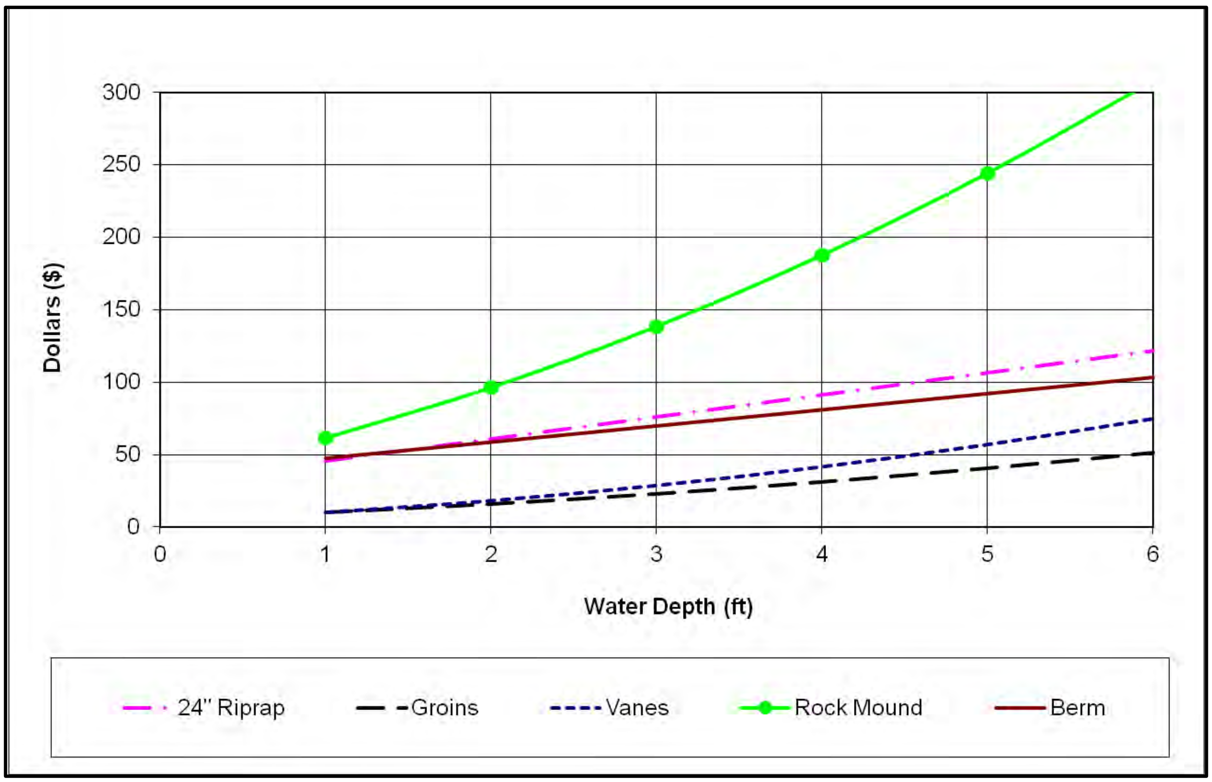


Figure 4-1. Rock-based Shoreline Stabilization Costs per Foot of Shoreline
(MVP Cost Data Based on 2011 Cost Estimates From *The Capoli Slough HREP*)

The cost data presented in the previous paragraphs, approximated from MVP data, assists in determining the relative cost effectiveness of the different types of bank stabilization. However, it is important to note that true cost will vary significantly depending on the location of the project. Additionally, rock costs will vary depending on the gradation selected, the location of the nearest USACE approved quarry, and the ability to transport the material to the site.

C. SHORELINE STABILIZATION TECHNIQUE DESIGN DETAILS

1. Rock Revetments. Placement of a rock revetment is shown in photographs 4-8, 4-9 and 4-10. Generally, two types of rock revetments are used:

> **Revetment 1** (Graded Riprap, 18 inches thick, 1V:2.5 to 3H side slope, with geotextile fabric) can be used on new construction such as islands or dikes.
>
> **Revetment 2** (Rock fill, 24 - 36 inches thick, 1V:1.5 to 3H side slope, no filter) can be used on new construction or existing shorelines which have variable slopes. The greater thickness of revetment 2 prevents piping of bank material, so no filter is required. As EMP designs have evolved, the thickness of revetment 2 has migrated from 36 inches to 24 inches. Based on observations of existing revetments in the MVP, a 24-inch thickness is sufficient. Typical design ranges are presented in table 4-6 and a profile detail is shown in figure 4-2. If the area will be subjected to ice action, the side slopes should be flattened to at least 1V: 4H.

Photograph 4-8. Long Island Bankline Prior to Rock Placement

Photograph 4-9. Placement of Rock Revetment at Long Island

Photograph 4-10. Area of Rock Placement at Long Island 8 Years Post Construction

Table 4-6. Typical Rock Revetment Design Criteria

Rock Slope	Thickness With Geotextile	Thickness W/out Geotextile	Height Above Normal Pool
1V:1.5H – 3H	18 inches	24 – 36 inches	1 – 5 feet

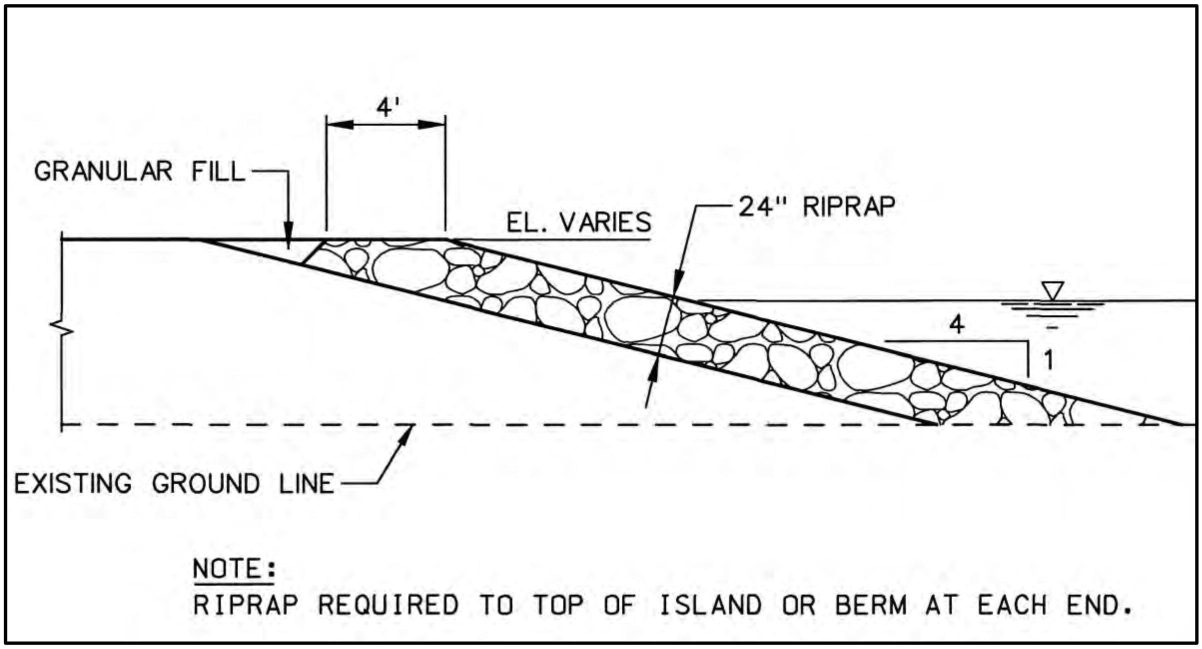


Figure 4-2. Rock Revetment Design Detail

CASE STUDIES AND LESSONS LEARNED

CASE STUDY 1. Rock Revetment - Lake Onalaska, Mississippi River Pool 7
Year Constructed - 1989

Rock Slope	Thickness	Height Above Normal Pool	10-yr Flood Height	Geotextile (ft)	Length
1V:3H	18 inches	5.0 feet	4.0 feet	Yes	7,370 feet

Lessons Learned: Portions of the 18" layer of rock (w filter fabric) placed at a 1V:3H slope were severely damaged by ice action during winter freeze-thaw expansion and spring break up. Subsequent maintenance involved placing additional rock over the damaged rock at a 1V: 4H slope. This has also been damaged by ice; however the rock thickness is adequate to prevent exposure of the underlying granular material.

Geotextile filter fabric placed on a 1V:3H slope was easy to install and resulted in an adequate filter.

CASE STUDY 2. Rock Revetment - Polander Lake, Stage I, Mississippi River Pool 5A
Year Constructed - 2000

Rock Slope	Thickness	Height Above Normal Pool	10-yr Flood Height	Geotextile (ft)	Length
1V:1.5 1V:3H	32	3.0 - 5.0 feet	8.5 feet	No	1,120 feet

Lesson Learned: The 32" layer of rock (without filter fabric place at slopes varying from 1V:1.5H to 1V:3H has been stable.

CASE STUDY 3. Rock Revetment - Pool 8, Mississippi River Phase I
Year Constructed - 2000

	Rock Slope	Thickness	Height Above Normal Pool	10-yr Flood Height	Geotextile (ft)	Length
Boomerang	1V:3H	18/27 inches	4.5 feet	4.5 feet	Yes	
Grassy	1V:3H	18/27 inches	2.5 feet	4.5 feet	Yes	780 feet
Horseshoe	1V:3H	18/27 inches	4.5 feet	4.5 feet	Yes	

Lessons Learned: The 18" layer of rock (w filter fabric) placed at a 1V:3H slope has been stable.

Waiting a year before designing the riprap allowed the Project Delivery Team to pinpoint erosion locations exactly. This resulted in a minimal amount of rock being needed along the outer edge of this island.

2. Rock Groins. Rock groins, shown in Photographs 4-11 and 4-12, are used mainly on new construction in shallow water where wave action and littoral drift are the dominant processes. Groins are placed perpendicular to the shoreline. After groins are constructed, shoreline reshaping occurs with deposition occurring near the groins and erosion occurring in the reach between two groins. This continues until a stable scalloped shape is formed. The erosion that occurs is usually acceptable for new construction, but is not acceptable on natural shorelines. The advantage of groins is cost savings (if in shallow water), creation of littoral and beach habitat, and an aesthetically pleasing shoreline.

Photograph 4-11. Newly Constructed Rock Groin in Pool 8

Photograph 4-12. Constructed Rock Groin in Pool 8 After a Few Years of Vegetation Growth)

The ratio of groin spacing to groin length varies from 4 to 6 for habitat projects. The height of rock groins varies from 1.5 to 2 feet above the average water surface. Table 4-7 shows typical design criteria and figure 4-3 shows an example design detail from Spring Lake Islands.

Table 4-7. Typical Rock Groin Design Criteria

Top Width	2 – 5 feet
Rock Slope	1V:1.5H – 2H
Height Above Average Water Surface Elevation	1.5 – 2 feet
Groin Length	30 – 40 feet
Groin Spacing	120 – 240 feet
Ratio of Groin Spacing to Groin Length	4 – 6 feet
Key-in	5 – 10 feet

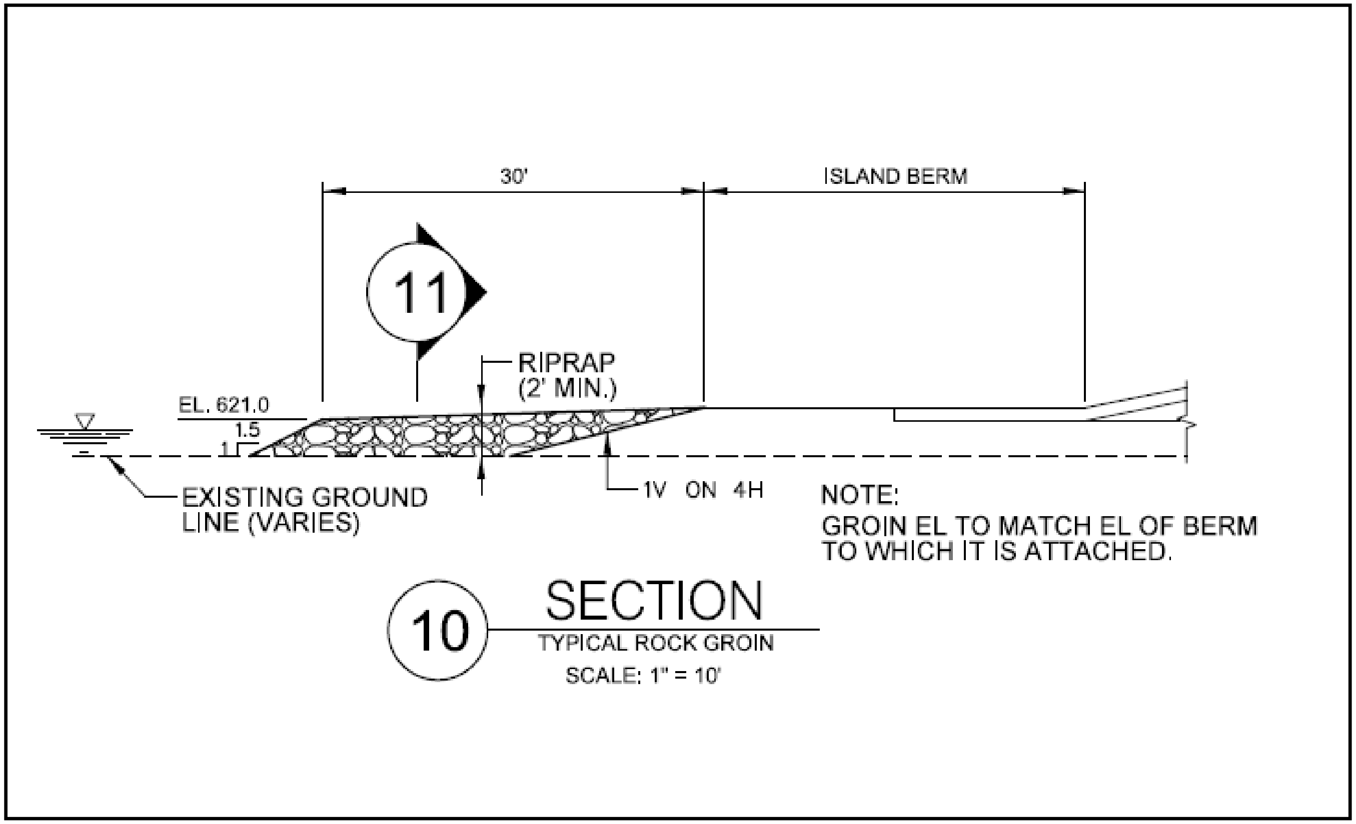


Figure 4-3. Rock Groin Design Detail

CASE STUDIES AND LESSONS LEARNED

CASE STUDY 4. Rock Groins - Weaver Bottoms, Mississippi River, Pool 5
Year Constructed - 1986

	Top Width	Rock Slope	Height Above Normal Pool	Groin Length	Groin Spacing	Length
Mallard Island	3 feet	1V:1.5H	1.5 feet	30 feet	150 feet	~5,600 feet
				30 feet	150 – 270 feet	
Swan Island	3 feet	1V:1.5H	1.5 feet	45 feet	180 feet	

Lessons Learned: Rock groins were built several years after the islands were constructed. These have stabilized the shorelines of Mallard and Swan Is. Some ice damage has occurred to the groins on Swan Is.

CASE STUDY 5. Rock Groins - Trempealeau National Wildlife Refuge, Mississippi River, Pool 6
Year Constructed – 1996/2003

Top Width	Rock Slope	Height Above Normal Pool	Groin Length	Groin Spacing	Length
3 feet	1V:1.5H	2 feet	30 feet	150 feet	7,600 feet

Lessons Learned: Severe ice damage displaced these groins, rendering them ineffective. These groins were re-built in 2003 using a flatter a 1V:5H end slope to cause ice to deflect up over the groins. So far this retro-fit seems to be working.

CASE STUDY 6. Rock Groins - Pool 8, Mississippi River Phase I
Year Constructed - 1992

Top Width	Rock Slope	Height Above Normal Pool	Groin Length	Groin Spacing	Length
2 feet	1V:2H	1.5 feet	30 feet	180 feet	~5,700 feet

Lessons Learned: The groins placed along these shorelines have effectively stabilized over a mile of shoreline.

3. Rock Vanes. As shown in photograph 4-13 and figures 4-4 and 4-5, rock vanes extend upstream from the shoreline and feature a sloping top elevation. As vanes are overtopped, they function as weirs and redirect flow away from the shore. Vanes are effective on shoreline adjacent to moving current

In many situations, vanes also function as groins by reducing littoral drift due to wind-driven wave action. Because of this dual function, the angle of the vane with the upstream shoreline is fairly large (45 to 60 degrees).

Vanes with angles ranging from 45 to 60 degrees have been constructed in an attempt to identify if there is an optimal angle for vanes on a large river system. In general, the vanes have not been in place long enough to draw a definitive conclusion. However, the vanes currently in place do seem to be performing well.

Currently, three types of vanes have been utilized: traditional, traditional with a root wad, and a J-Hook Style. Plan and profile views for a traditional vane are provided in figures 4-4 and 4-5.

Photograph 4-13. Rock Vanes at Lost Island Chute, Pool 5

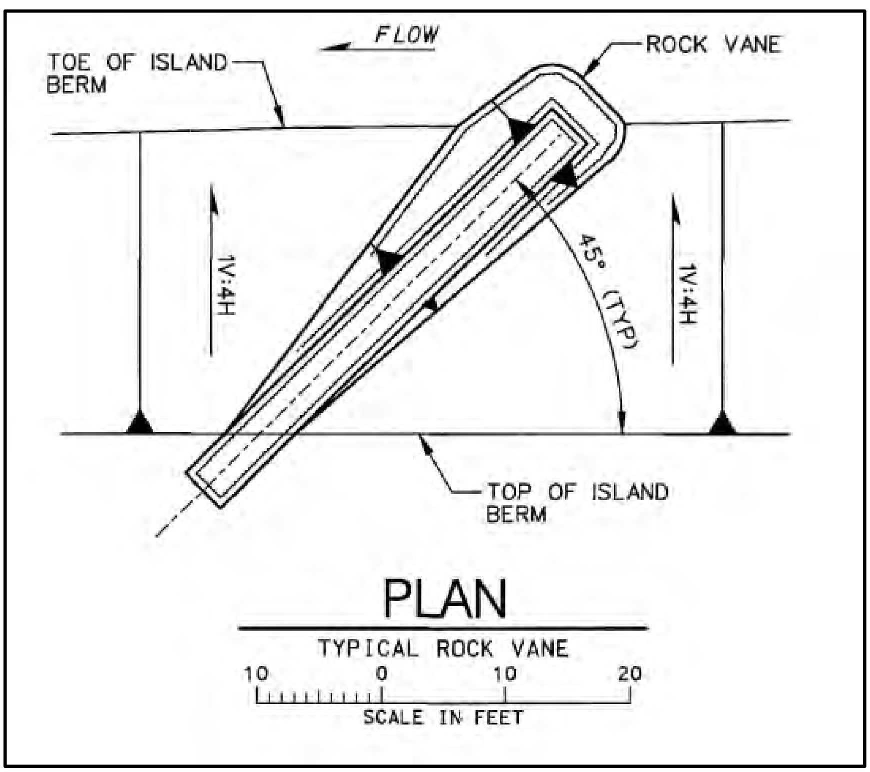


Figure 4-4. Plan View of a Vane Alignment

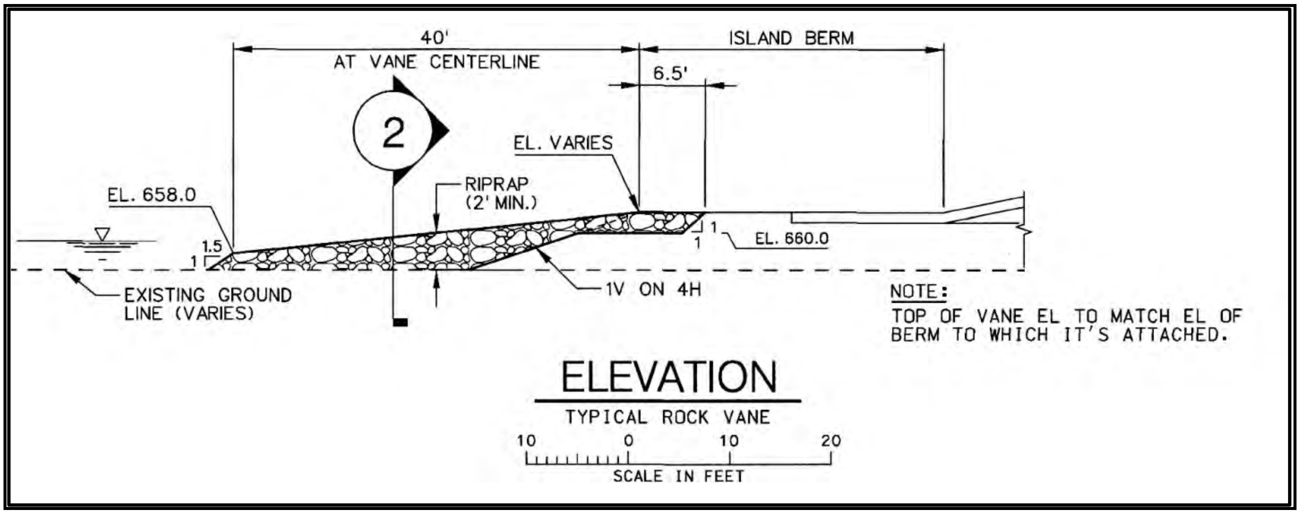


Figure 4-5. Typical Detail of a Rock Vane

The plan view of a J-Hook style vane is shown in figure 6 and photograph 4-14. While the application of J-Hook vanes has been successful in the MVP, applications further down river have encountered performance issues. The increased scour created by the hook of the J caused the structure to cave into itself. The J-hooks also require almost double the material of a rock vane while providing similar protection. These structures may be better served in a smaller stream.

Typical design criteria are presented in table 4-8.

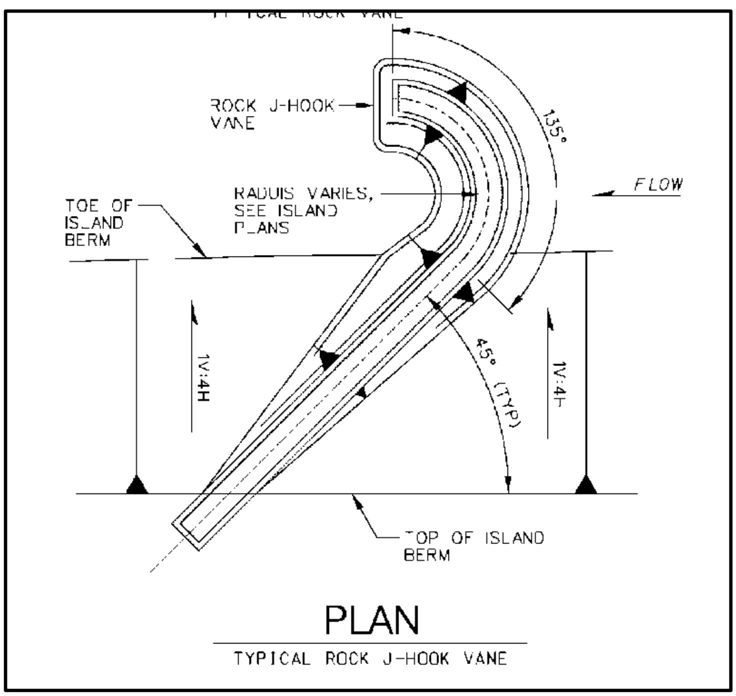


Figure 4-6. Plan View of a J-Hook Vane

Photograph 4-14. J-Hook Vane in Pool 8

Table 4-8. Typical Vane Design Criteria

Top Width	3 – 5 feet
Rock Slope	1V:1.5H – 3H
Height Above Average Water Surface Elevation	1.5 – 2 feet
Top Elevation Slope	10 – 12%
Length	30 – 45feet
Hook Length (J-Hook vanes only)	30 – 45
Angle (□)	40 – 55
Spacing Ratio (Length to Spacing)	1:3 - 4

CASE STUDIES AND LESSONS LEARNED

CASE STUDY 7. Rock Vanes - Lost Island Chute, Mississippi River Pool 5
Year Constructed – 2000

	Top Width	**Rock Slope**	**Height Above Normal Pool**	**Groin Length**	**Groin Spacing**	**Angle**	**Length**
Sec 1	3 feet	1V:1.5H	2 feet	30 feet	80 feet	45°	400 feet
Sec 2	3 feet	1V:1.5H	2 feet	30 feet	120 feet	45°	480 feet

Lessons Learned: The vanes appear to have stabilized the shoreline though some reshaping is still occurring. The 80-foot spacing could have been a little larger.

CASE STUDY 8. Rock Vanes - Spring Lake Islands, Mississippi River Pool 5
Year Constructed – 2006

	Top Width	**Rock Slope**	**Height Above Normal Pool**	**Groin Length**	**Groin Spacing**	**Angle**	**Length**
Island 4	4 feet	1V:1.5H	2 feet	30 feet	100 feet	45°	14,000 feet

Lessons Learned: The vanes on Island 4 were placed too close to the deep channel. The shoreline eroded farther than anticipated and almost cut behind the key-in. The PDT did not pursue remedial measures and even though this island has been overtopped twice since construction, the shoreline on island 4 has remained stable.

4. Offshore Rock Mounds. Offshore rock mounds, shown in photograph 4-15 and figure 4-7, are used on natural shorelines in four situations:

1. shorelines with shallow nearshore bathymetry which prevents access by marine plant
2. low shorelines or marsh area where there is not a well defined shoreline (i.e. river bank) to place revetment on or tie groins or vanes into
3. shorelines with shallow nearshore bathymetry where it is desirable to get the outside toe of the rock into deeper water to prevent undercutting
4. shorelines with heavy wood debris that would prevent the direct placement of rock

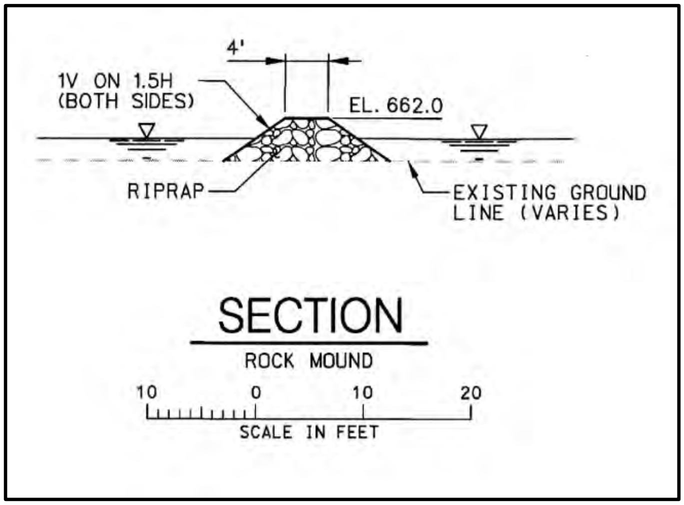


Figure 4-7. Offshore Rock Mound Design Detail.

Photograph 4-15. Offshore Rock Mound at Peterson Lake in Pool 4

Design criteria for offshore rock rounds are presented in table 9.

Table 4-9. Typical Offshore Rock Mound Design Criteria

Top Width	3 – 5 feet
Rock Slope	1V:1.5H – 3H
Height Above Average Water Surface Elevation	1.5 – 2 feet

CASE STUDIES AND LESSONS LEARNED

CASE STUDY 9. Offshore Rock Mound - Weaver Bottoms, Mississippi River Pool 5
Year Constructed - 1986

	Rock Back Slope	Rock Front Slope	Height Above Normal Pool	10-yr Flood Height	Top Width	Length
Swan Island	1V:1.5H	1V:1.5H	3.0 feet	4.0 feet	3.0 feet	800 feet

Lessons Learned: Offshore rock mounds will decrease in elevation with time due to substrate displacement, ice action, toe scour, or some combination of factors. This happened on the north side of Swan Island, and resulted in a decrease in mound elevation of at least 1 foot during the first 5 years of the project. Because the rock mound had been constructed fairly high initially, it continued to reduce wave action at the toe of the island.

Construction access to various shoreline reaches was a significant and contentious issue during plans and specs development. Requiring marine access would have entailed significant amounts of dredging. However gaining access by traveling on top of the island would have destroyed terrestrial vegetation.

CASE STUDY 10. Offshore Rock Mound - Polander Lake, Mississippi River Pool 5A
Year Constructed - 2000

Rock Back Slope	Rock Front Slope	Height Above Normal Pool	10-yr Flood Height	Top Width	Length
1V:1.5H	1V:3H	4.5	8.5	3.0	600 feet

Lessons Learned: An offshore rock mound was constructed to act as breakwater to prevent wave action from impacting a portion of the backwater. The rock mound has been stable.

5. Rock-Log Structures. In protected areas with minimal ice impacts, rock-log structures provide an economical alternative to offshore rock mounds. These structures protect existing shoreline while providing woody structure for fish and loafing areas for wildlife. Photographs 4-16 and 4-17 show a typical rock-log structure application.

Photograph 4-16. Installation of a Rock log Structure

Photograph 4-17. Rock-log Structure in Place

The minimum rock cover required to anchor the logs in place is provided in table 4-10.

Table 4-10. Typical Rock-log Structure Design Guidance

Top Elevation	Varies
Minimum Rock Cover if 15' of Tree is Covered	2 feet
Minimum Rock Cover if 20' of Tree is Covered	1.5 feet
Minimum Length of Rock Cover with Geogrid	5 feet
Rock Slope	1V:2H
Height of Tree Trunk Above the Bottom	2 – 2.5 feet

CASE STUDIES AND LESSONS LEARNED

CASE STUDY 11. Rock-Log Structure - Rosebud Island, Mississippi River Pool 7
Year Constructed - 2001

Rock Back Slope	Rock Front Slope	Height Above Normal Pool	Rock Top Width	Length
1V:2H	1V:2H	2 feet	3 feet	140 feet

Lessons Learned: After the initial design was done, a design was developed that involved the use of a geo-grid placed over the logs, with rocks subsequently placed on the geo-grid. This reduced the length that each log had to be covered to 5 feet. The geo-grid has worked well. Using two logs instead of three would have left some space for water to flow under the logs.

6. Berms and Vegetation

a. Design Criteria. One of the primary purposes of the berm is to provide conditions for the growth of woody vegetation, which reduces wave action on the main part of the project feature (e.g. island or dike) during floods. Although colonization by woody plants will occur naturally, sandbar willow (*salix exigua*) is usually planted on berms to increase the rate of colonization. Within a few years, the willows usually spread to cover 20 or 30 feet of the berm and side slopes. Other species such as False Indigo and Willow hybrids have been used in smaller quantities.

Photograph 4-18. Pool 5, Weaver Bottoms, Swan Island.
Native prairie grasses were planted to provide nesting habitat and stabilize the top of the island.

Table 4-11. Berm Design Criteria

Top Width	20 – 50 feet
Slope	1V:4H – 5H
Height Above Normal Water Surface Elevation	2.5– 3 feet

CASE STUDIES AND LESSONS LEARNED

CASE STUDY 12. Berms – Boomerang Island, Phase I, Mississippi River Pool 8
Year Constructed - 1992

Waterline to Transition Slope	Transition to Top of Island Slope	Height Above Normal Pool	Top Width	Length
1V:20H & 1V:13H	1V:5H	4 feet	45 feet	~3miles

Lessons Learned: Constructing low berms results in rapid colonization by woody vegetation, increasing island stability during floods. Over three miles of shoreline were stabilized using berms, groins, and vegetation. Within a few years willow growth on the berm spreads from the water line to almost the top of the island, providing a 20- to 30-foot swath of willows.

b. Large Woody Debris. Islands and associated shoreline stabilization structures provide loafing habitat for many species. The Fish and Wildlife Work Group established the following parameters for using large woody debris:

The main trunk of the tree should be a minimum of 25 feet long and gently sloped so that with changing water levels there are loafing areas available most of the time. A mixture of elevations is best, due to the different preferences and capabilities of different species. Generally, these structures should be placed in areas sheltered from wind generated waves. These structures can be placed in sand or anchored into the shoreline with a rock key-in. Example design details of large woody debris are shown in figures 4-8 and 4-9.

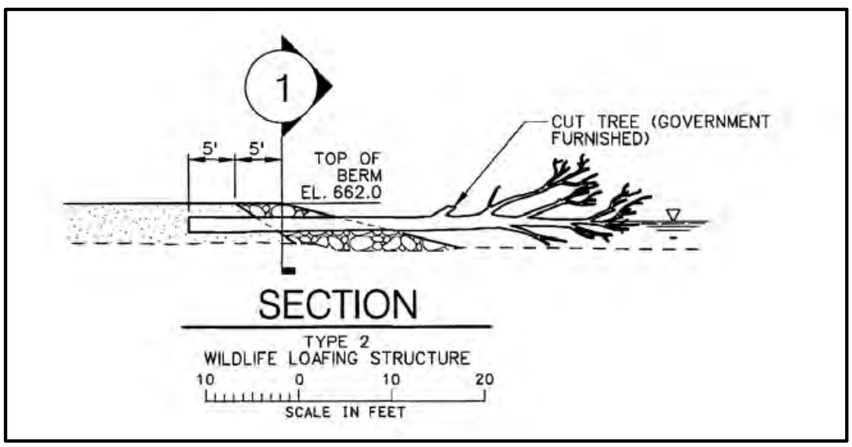


Figure 4-8. Design Detail of Large Woody Debris

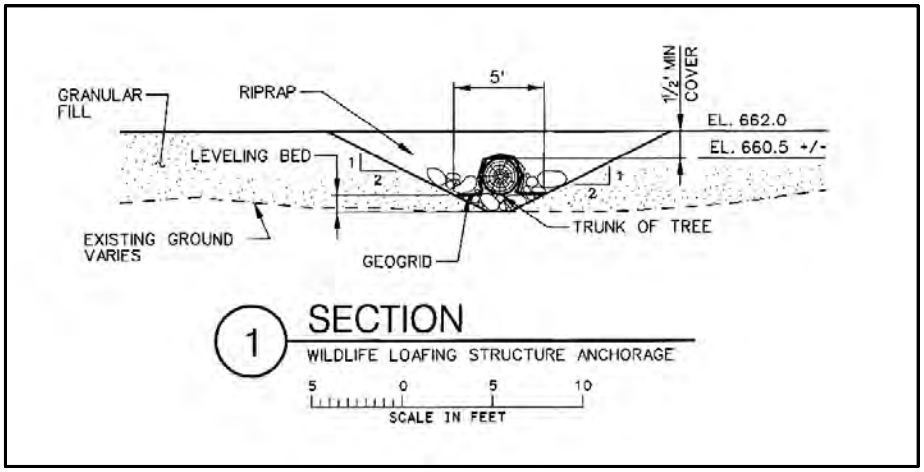


Figure 4-9. Design Detail of Large Woody Debris Anchorage

Table 4-12. Typical Large Woody Debris Design Criteria

Height Above Summer Pool	2 – 12 inches
Length of Tree	> 25 feet
Diameter of Tree	10 – 24 inches
Preferred Species	Black Locust/White Oak
Location	Sheltered Backwaters/Secondary Channels
Number	Multiple Trees May Be Used In One Application

CASE STUDIES AND LESSONS LEARNED

CASE STUDY 13. Large Woody Debris - Spring Lake Islands, Mississippi River Pool 5
Year Constructed - 2006

	Berm Key-in	Minimum Rock Cover	Height Above Normal Pool	Geogrid	Location
Island 2	10 feet	1.5 feet	0 – 0.5 feet	Yes	Mudflat

Lessons Learned: The Mississippi River distributes large woody debris during high water events. If the project location is likely a deposit area for large woody debris during high water events, including them as a project feature may not be necessary.

D. PLANS AND SPECIFICATIONS

1. Surveys. Surveys of the eroded area should be taken at set intervals starting at the top of bank and continuing to the point at which the bank slope flattens below the average water surface elevation. Lengths of eroded areas should also be surveyed.

2. Plans. Drawings should include a plan view of the site indicating the length of protection. Drawings should also include select survey transects, and a typical section. Drawings should show expected slopes, thickness of rock, and rock gradation size. A typical drawing is shown in figure 4-10.

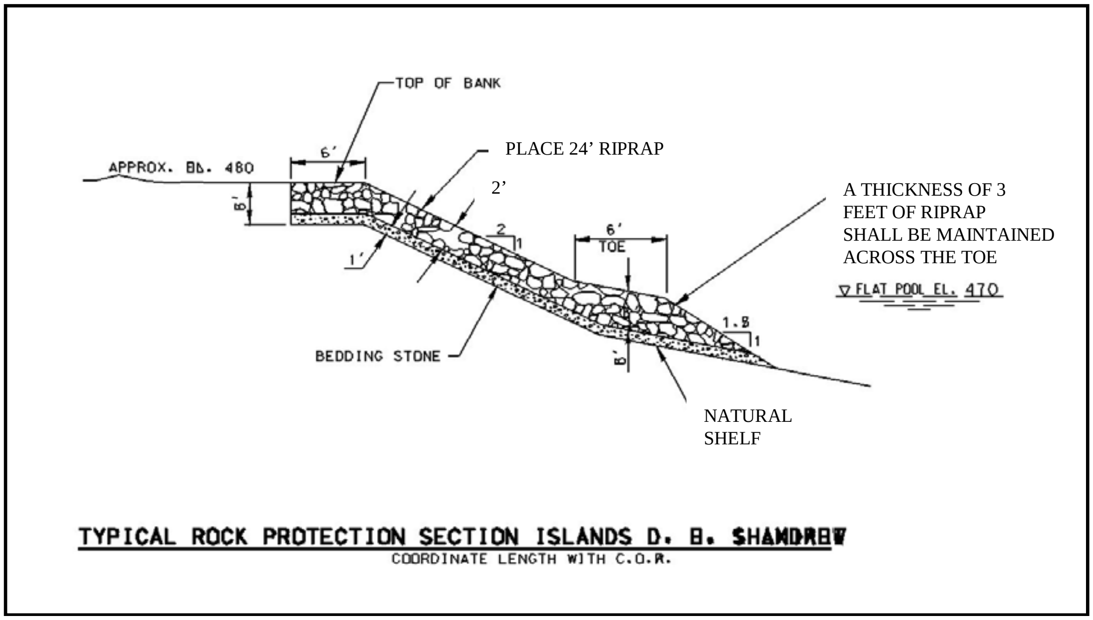


Figure 4-10. Typical Rock Protection Section

3. Quantities. As a general rule of thumb, once the cubic yards of material are estimated (through Micro station, Inroads, or simple geometry), the following equations can be used to estimate tons of material required:

Equation 2-1: Cubic Yards of Material * Y = Expected Rock Weight
where:
Y(MVP) = 1.45 tons/CY material
Y(MVR) = 1.65 tons/CY material,
Y(MVS) = 1.5 – 1.6 tons/CY material (for graded riprap),
Y(MVS) = 1.6 – 1.7 tons/CY material (for bedding material).

E. ROCK SIZING AND DESIGN CONSIDERATIONS

Basic guidance for shoreline stabilization rock sizing and riprap design is presented in EM 1110-2-1601 (EM 1601) and the Coastal Engineering Manual. Typically, Hydraulics will analyze required rock size and thickness for erosion due to flow and wave wash, and Geotech will establish the gradation and verify the thickness.

While it is important to ensure the riprap and rock sections resist the primary method of erosion, in general, EMP projects should incorporate more risk than Flood Control or Section 14 projects. Rock sizing and layer thickness determined by using either of these manuals should be considered the maximums for an EMP project. Project design teams should investigate opportunities to minimize rock size and thickness.

However, in some cases it may be desirable to have a larger rock gradation. Surveys done by the MVP (Niemi & Strauser, 1992) indicate that rock gradations that include larger rocks and subsequently larger voids improved habitat for fish. Another consideration, if near shore depths are relatively deep, might be incorporating woody structure into the design to provide fish cover.

1. Gradation and Thickness. Design criteria for rock gradation and thickness vary depending on the location of the project site. Each District has specific concerns and guidelines that need to be addressed. For this reason, gradation and thickness will be presented by district (St. Paul, Rock Island, and St. Louis).

2. St. Paul. Table 4-13 shows typical rock gradations used by MVP for riprap, vanes, and groins. The standard gradation, which is similar to ASTM R-60, was established based on ease of obtaining it from quarries and the requirements for wave action which is the primary erosive force affecting river shorelines. The large gradation has been used when wind fetch exceeded 2 miles, ice action was expected to be a problem, or a potential for vandalism (i.e. movement of rock by people) existed. The cobble gradation was used to repair sections of the Pool 8, Phase II islands that were damaged during the 2001 flood, and is being used to create mussel habitat at the Capoli Slough project. The river-washed stone gradation was used in the Pool 8, Phase III project and is being used to create mussel habitat at Capoli Slough. These sections were not exposed to significant wave action and field reconnaissance indicated that while sand size material had been eroded during overtopping, gravel-size material and larger was stable, so a cobble gradation was used.

Table 4-13. St. Paul District Rock Gradations Used on HREP Projects.

Limits of Stone Weight for Percent Lighter by Weight	Standard Gradation	Large Gradation	River Washed Stone	Cobbles
W100 Range (lbs)	300 to 100	630 to 200	25 to 6	16 to 8
W50 Range (lbs)	120 to 40	170 to 70	10 to 3	7 to 4
W15 Range (lbs)	25 to 8	60 to 15	5 to 0.5	3 to 1

Layer thickness (T) should equal 1 times $D_{100,max}$ or 1.5 times $D_{50,max}$, whichever results in the greater thickness.

3. Rock Island. MVR designs rock protection in accordance with EM 1110-2-1614 *Design of Coastal Revetments, Seawalls, and Bulkheads*.

4. St. Louis. Stone gradations used for MVS HREP projects are primarily graded riprap called graded stone “B” and “C”. Depending upon specific site design considerations, bedding material and/or geotextile will be used in the design section. Gradations and standard thickness for these materials are presented in table 4-14, 4-15, and 4-16.

Table 4-14. St. Louis District Bedding Material Gradation[1]

U.S. Standard Sieve	Percent by Weight Passing
3 inch	90 – 100
1.5 inch	35 – 70
No. 4	0 – 5

[1] Standard Bedding Material thickness ranges from 8 to 12 inches.

Table 4-15. St. Louis District Graded Stone B Gradation[1]

Limits of Stone Weight, lbs, for Percent Lighter by Weight	Stone Weight
100 (lbs)	1200 lbs
72 – 100 (lbs)	750 lbs
40 – 65 (lbs)	200 lbs
20 – 38 (lbs)	50 lbs
5 – 22 (lbs)	10 lbs
0 – 15 (lbs)	5 lbs
0 – 5 (lbs)	<5 lbs

[1] Standard thickness for the Graded Stone B gradation ranges from 30 – 42 inches.

Table 4-16. St. Louis District Graded Stone C[1] Gradation. [2]

Limits of Stone Weight, lbs, for Percent Lighter by Weight	Stone Weight
100 (lbs)	400
70 – 100 (lbs)	250
50 – 80 (lbs)	100
32 – 58 (lbs)	30
15 – 34 (lbs)	5
2 – 20 (lbs)	1
0 – 5 (lbs)	<5

[1] Standard thickness for the Graded Stone C gradation ranges from 18 to 24 inches.
[2] 5% of the material can weigh more than 400 lbs. No piece shall weigh more than 500 lbs.

Additional design considerations for shoreline stabilization techniques involving the use of rock are provided in table 4-17.

Table 4-17. Other Design Considerations for Rock

Design Consideration	General Guidance for EMP Designs
Toe Protection	"When designing a riprap section to stabilize a streambank, the designer accounts for scour in one of two ways: 1) by excavation to the maximum scour depth and placing the stone section to this elevation, or 2) by increasing the volume of material in the toe section to provide a launching apron that will fill and armor the scour hole. Preference should usually be given to option (2) because of ease of construction and lower cost, and because of environmental impacts associated with excavation of the streambed." (ERDC/EL TR-03-4) • Typically, the toe extends 6 feet once the slope flattens.
Filter or Bedding	Filter or bedding should be used if soil movement through the riprap is a concern. Guidance for filter design is provided in EM 1110-2-1901, Appendix D. • Filter fabric may be eliminated if thickness of riprap layer is doubled.
Side Slopes	Based on guidance provided in EM 1601, riprap section side slopes should not be steeper than 1V on 1.5H. • 1V on 2 - 3H is preferred.
Shoreline Key-in	• A key-in to the existing shoreline of 5 – 10 feet is recommended for riprap stabilization.
Field Stone	When rounded stone is used instead of angular stone, the D_{50} calculated for angular stone should be increased by 25%.
Wave Action Prop Wash	If the riprap section will need to withstand the forces created by the prop of a tow, riprap size should be determined by using the guidance provided in "Bottom Shear Stress from Propeller Jets" (Maynord).
Ice Action	• Rock slopes should be 1V:4H or flatter • Maximum rock size should be increased to 2*ice thickness (Sodhi).
Underwater Placement	• When riprap is placed underwater, the layer thickness should be increased by 50 percent, but the total thickness should not be increased by more than 12 – 18 inches. • If the depth of water is less than 3-4 feet and good quality control can be achieved, a 25% increase in layer thickness is adequate.
Construction Accessibility	Many sites requiring stone may be located in remote, shallow areas. Access to the site must be available for truck or barge. If access to the site is being achieved by land routes, consideration should be given to the viability of the existing access roads. This should include, but is not limited to, load limits, disruption of typical traffic patterns, and coordination with local officials. Additionally, sufficient water depth may require dredging before stone can be placed, and trees may need to be removed before the bankline is cut back or rock is placed.
Construction Techniques	Placement of smaller stone in a fast moving current could cause a significant loss of stone. Ensure that stone is sized in accordance with the conditions in which it will be placed.
High Turbulence Conditions	If the area being protected is subject to high turbulence, plate 29 from EM 1601 (v.1970) should be used for rock sizing and design.

F. REFERENCES

Chen, Y. H. and D. B. Simons, 1979. Geomorphic Study of Upper Mississippi River. Journal of the Waterway, Port, Coastal, and Ocean Division. American Society of Civil Engineers, Vol. 105, No. WW3

Collins, M. J., and J. C. Knox, 2003. Historical Changes in Upper Mississippi River Water Areas and Islands. Journal of the American Water Resources Association. Paper No. 01221

Maynord, Stephen T, *Bottom Shear Stress from Propeller Jets*. Ports 1998 Conference Proceedings, Vol. 1, 199

Niemi, J.R. and C.N. Strauser. 1992. Environmental River Engineering.

Sodhi, D.S., S.L. Borland, and J. M. Stanley, C. J. Donnelly. 1997. Ice effects on riprap: Small-scale tests. In Energy and Water: Sustainable Development, 27th International Association for Hydraulic Research Congress, San Francisco, pp. 162-167

EM 1110-2-1601, *Engineering and Design - Hydraulic Design of Flood Control Channels*, CECW-EH-D, Original document - 1 July 1991. Change 1 - 30 June 1994

EM 1110-2-1204, *Engineering and Design - Environmental Engineering for Coastal Shore Protection*, CECW-EH, 10 July 1989

EM 1110-2-1614, *Design of Coastal Revetments, Seawalls, and Bulkheads*, June 1995

US Army Corps of Engineers, Rock Island District, Upper Mississippi River System Environmental Management Program 2004 Report to Congress, 2 August 2004.

US Army Engineer Waterways Experiment Station. 1984. Shore Protection Manual, 4th ed