UPPER MISSISSIPPI RIVER SYSTEM
ENVIRONMENTAL DESIGN HANDBOOK

CHAPTER 2

SHORELINE STABILIZATION

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UPPER MISSISSIPPI RIVER SYSTEM
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CHAPTER 2

SHORELINE STABILIZATION

2.1 Resource Problem

The Upper Mississippi River is island braided with many anastomosing 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. The river today is a reflection of many changes that have altered its natural condition (Chen & Simons, 1979, Collins & Knox, 2003). These include early attempts to create a navigation channel through the construction of river training structures, the conversion of the watershed to agricultural land-use, the urbanization of some reaches of the river, and the introduction of exotic species. However, the construction of the Locks and Dams in the 1930s is the most significant event affecting the condition of the river today and island construction is an attempt to reverse or alter the impacts of the locks and dams.

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 several factors caused a gradual decline in the habitat that had been created in the backwaters.

Sediment Deposition. With permanent submergence in the lower reaches of the navigation pools came the continual flow of water into the floodplain areas. As flow spread out in the backwaters, it lacked the energy to transport sediment through the backwaters, resulting in a depositional system. Sediment deposition was greatest near sediment sources such as the main channel, secondary channels, and tributaries. In numerous areas deltas have formed near these sediment sources and the habitat quality in these deltas is generally good. However, in most areas, sediment deposition has filled in aquatic habitat, and altered substrate characteristics so that aquatic plant growth is reduced. The system that was created by the locks and dams simply was not sustainable.

Permanent Submergence. Aquatic plants will colonize areas that have the right combination of water depth, velocity, and quality. Some species exist in low areas that are permanently submerged, while others exist at higher elevations that are submerged some of the time and are dry at other times. Variability in the annual water level hydrograph creates the condition that supports diverse aquatic plant communities. The problem in the lower reaches of the navigation pools is that there is little variation in water levels between low flow conditions and the bankfull flood. Maintaining a minimum pool elevation results in little area that ever dries out. Without this variability, and especially without the drought portion of the annual hydrograph, habitat quality has declined.

Shoreline Erosion. After the locks and dams were constructed, 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. In the middle reaches of the navigation pools, a significant hydraulic slope between the main channel and the backwaters exists. This has resulted in significant secondary channel formation and enlargement in many cases.

The effects of sediment deposition, loss of aquatic plant communities, and shoreline erosion has resulted in degraded habitat in the navigation pools.

2.2 General Design Methodology

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. Shoreline stabilization includes riprap (photograph 2.1), biotechnical methods (photographs 2.2 and 2.3) and vegetative stabilization (photograph 2.4). A description of these techniques is provided in table 2.1.

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 2.1. Lake Onalaska. Riprap and geotextile filter placed on sand.

Photograph 2.2. Pool 8, Phase II, Boomerang Island. Biotechnical stabilization with groins and willows.

Photograph 2.3. Weaver Bottoms, Swan Island. Biotechnical Stabilization with fiber rolls, sand bags, and willow mats.

Photograph 2.4. Pool 8, Phase II, Boomerang Island. Vegetative stabilization was used on over 60-percent of the shorelines on Boomerang Island.

2.2.1 Site Identification. Typically, the Project Design Team (PDT) works together to identify and prioritize areas requiring protection. In the St. Paul District of the Corps of Engineers, erosion assessments, using the worksheet provided in table 2.2, 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.

2.2.2. Shoreline Stabilization Technique Selection. Once a site has been identified, the type of shoreline stabilization needs to be determined. Although there is significant variation from project to project, a typical distribution is 20-percent riprap, 40-percent biotechnical, and 40-percent vegetative. More recent island projects tend to have less riprap and use more biotechnical and vegetative stabilization. On existing shorelines, riprap and off-shore mounds are used more often than groins or vanes. This is 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 2.3 lists the length of various types of shoreline stabilization used on islands that have been constructed.

Table 2.1. Description of Shoreline Stabilization Techniques

Riprap. 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. Riprap can be designed with a high degree of precision, thus its performance and cost can be predicted more reliably than many other methods. Stone conforms readily to irregularities in the bank, whether they are due to poor site preparation, subsequent scour, or settlement and loss of sub-grade material.

Biotechnical Methods. Biotechnical methods use a combination of live vegetation and structural material to strengthen the shoreline or reduce the erosive forces that act on the shoreline. Live vegetation consists of woody vegetation while structural material includes rock or log groins, vanes, or mounds, and a sand berm. The function of each of these features is discussed below.

Feature	Function
Groins	Contain littoral drift of berm material to area between two groins. This results in a scalloped shoreline shape, which is the shoreline adjustment to the prevailing winds.
Vanes	Redirect river currents away from the shoreline. Erosive secondary currents are moved away from the toe of the bank.
Off-Shore Mounds	Reduce erosive forces due to wave action, river currents, or ice action
Sand Berm	Function 1 - Reduce erosive forces on main part of island at low flows Function 2 - Provide sand for beach formation Function 3 - Provide substrate for woody vegetation growth Function 4 - Provide habitat and elevation diversity Function 5 - Increases slope stability of main island cross section.
Woody Vegetation (Willows)	Function 1 - Reduce erosive forces on the island due to wave action, river currents, or ice action during floods. Function 2 – Provide floodplain habitat. Function 3 – Increase the downwind sheltered zone created by the island. Function 4 – Provide a visual barrier between areas that typically get human disturbance (i.e. boats and tows) and the backwaters.

New shorelines (e.g. islands) usually include near-shore berms constructed along the shoreline. Near-shore berms eliminate or reduce erosive forces so that erosion of the shoreline is prevented for both low water and high water conditions. During low water conditions, near-shore berms provide a direct barrier between erosive forces and the shoreline. During high water conditions, the woody vegetation that grows on near-shore berms reduces erosive forces on the shoreline.

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. This is the same as the biotechnical designs discussed above except that groins, vanes, or mounds are not needed to stabilize the outer edge of the berm.

Other Biotechnical Methods. A number of other biotechnical methods have been used to a limited extent on shorelines to reduce erosion. These include the use of synthetic reinforcement grids, willow mats, and fiber or willow rolls for toe protection.

Table 2.2. Erosion Stabilization Assessment Worksheet

Erosion & Stabilization Assessment Worksheet			**Location: Embankment 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 -

Table 2.3. Shoreline Stabilization Length, and Percent of Total Length, Used on Island Projects

Island	Total Shoreline Length	Riprap Stabilization Length		Biotechnical Stabilization Length		Vegetative Stabilization Length		Year Construct
	(feet)	(feet)	(%)	(feet)	(%)	(feet)	(%)	
Weaver Bottoms	17400	2180	13	5670	33	9550	55	1986
Lake Onalaska	9540	7370	77	1280	13	890	9	1989
Pool 8, Phase I, Stage 1, Horseshoe	6900	600	9	0	0	6300	91	1989
Pool 8, Phase I, Stage 2, Boomerang	17330	1885	11	4600	27	10845	63	1992
Pool 8, Phase I, Stage 2, Grassy	2600	780	30	1100	42	720	28	1992
Willow Island	3700	900	24	1700	46	1100	30	1995
Pool 8, Phase II Eagle Island	5660	460	8	3450	61	1750	31	1999
Pool 8, Phase II Slingshot I	10800	600	6	7520	70	2680	25	1999
Pool 8, Phase II Interior Islands	4700	800	17	3900	83	0	0	1999
Polander Lake, Stage 2 Barrier Islands	10,000	1000	10	4600	46	4400	44	2000
Polander Lake, Stage 2 Interior Islands	4210	120	3	0	0	4090	97	2000
Long Island (Gardner) Div.	3765	3765	100	0	0	0	0	2001
Pleasant Creek	1500	1500	100	0	0	0	0	2001
Lake Chautauqua								1999
Average			**22%**		**35%**		**43%**	

2.2.3. Cost. Shoreline stabilization costs include earth fill (granular and fines) for the berm, rock, and the cost of willow plantings. Figure 2.1 shows estimated costs, based on data collected by the St. Paul District, for constructing various types of rock based shoreline stabilization in water depths of 1 to 6 feet. The berm cost must be added to the cost of the various types of rock structures. 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.

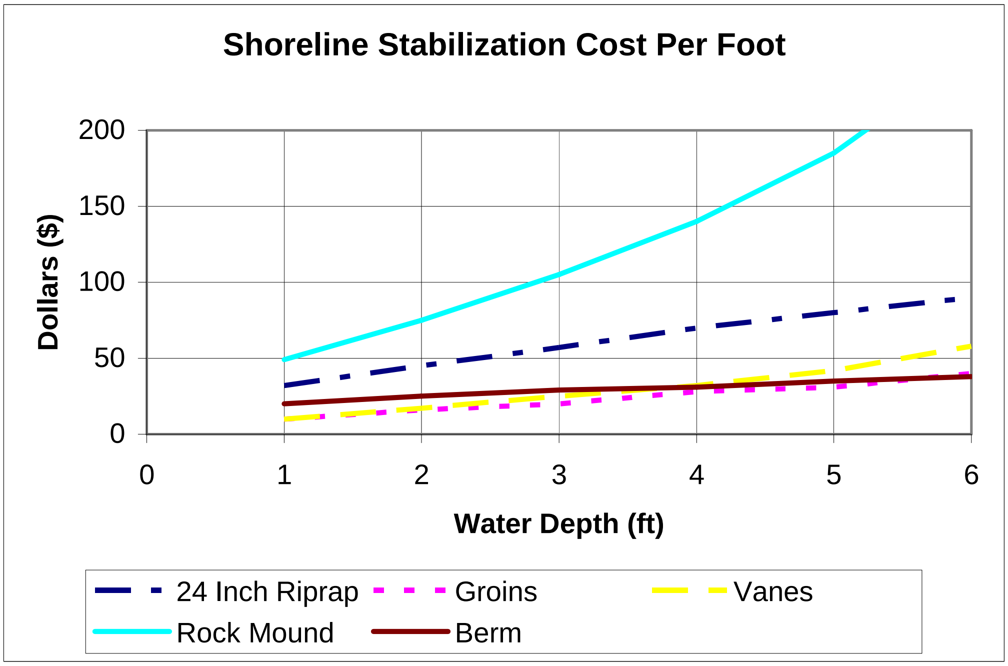

Figure 2.1. Rock Based Shoreline Stabilization Costs Per Foot of Shoreline (MVP Cost Data)

Assumptions for cost estimates displayed in Figure 2.1

1. Rock cost equals $35/ton or $49 cubic yard in place
2. Sand cost equals $3/cubic yard
3. Fines cost equals $12/cubic yard
4. Height of rock structures above average water surface is 2 feet.
5. Side slope of 24 inch rock fill equals 1V:3H
6. Side slope of groins, vanes, and rock mound equals 1V:1.5H
7. Top width of groins, vanes, and rock mound equals 4’
8. Groin and vane length is 30 feet, and spacing is 180 and 90 feet respectively
9. Berm width equals 30 feet, half the berm (15 feet) is covered with topsoil to a depth of 1 foot, and willow cost is $2 per foot for 2 rows of willows.

As is shown in table 2.4, 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 2.4. Cost of Willow Plantings on Two Island Projects

Project	Bid Price	Shoreline Length	Cost per foot
Pool 8, Phase II	$29,000	19,300	$1.50
Polander Lake	$8,400	3,750	$2.24

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. As an example of the difference in true costs, MVS material cost data is presented in table 2.5 and recent shoreline stabilization project costs are presented in table 2.6.

Table 2.5. MVS Material Costs (2005 price level)

Material	Cost ($)	Description
Riprap	$22 - $30/ton	In-place, graded, trucked < 10 miles
Riprap	$14 - $20/ton	In-place, delivered by floating plant
Bedding	$16 - $18/ton	In-place, trucked < 10 miles
Bedding	$12 - $16/ton	In-place, delivered by floating plant
Sand	$4/yd^3	Dredged in-place
Fine Gradations of Rock	$16/ton	
Clay	$7/yd^3	

Table 2.6. Costs of Recent Shoreline Stabilization Projects

Project	Year Constructed	Feature	Length (feet)	Cost ($)	Cost/Foot
Lake Chautauqua	2001	Riprap		$362,250	
Long Island Gardner Division	2001	Riprap	3765	$2.53M	$6732
Pleasant Creek	2001	Riprap	1500		

2.3 Plans and Specifications

2.3.1. 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.

2.3.2.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 2.2.

2.3.3. Quantities. As a general rule, once the cubic yards of material are estimated (through Microstation, 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(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).

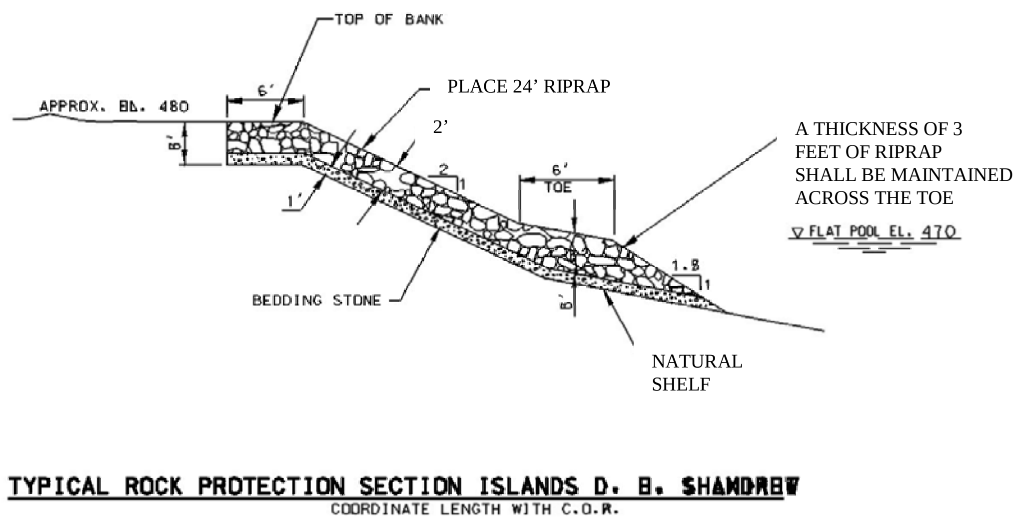

Figure 2.2. Typical Rock Protection Section

2.4 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 Shore Protection Manual (SPM). Typically, Hydraulics will analyze required rock size and thickness for erosion due to flow and Geotech will analyze required rock size and thickness for erosion due to wave wash.

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 St. Louis District, Corps of Engineers (Niemi and 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.

2.4.1. 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).

2.4.1.1. St. Paul. Typical rock gradations used by MVP for riprap and groins are given in table 2.7. 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 existed. The cobble gradation was used to repair a couple of sections of the Pool 8, Phase II islands that were damaged during the 2001 flood. 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 2.7. St. Paul District Rock Gradations Used on HREP Projects

Limits of Stone Weight, in Pounds, for Percent Lighter by Weight	Standard Gradation	Large Gradation	Cobbles
W100 Range (lbs)	300 to 100	630 to 200	9 to 5
W50 Range (lbs)	120 to 40	170 to 70	4 to 2.5
W15 Range (lbs)	25 to 8	60 to 15	2 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.

2.4.1.2. Rock Island. MVR often uses a gradation with 400lb top size rock or IDOT Gradation No. 5. A 24 inch layer of riprap is applied over a 12 inch bedding layer of CA6 gravel.

2.4.1.3. 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 following tables 2.8, 2.9, and 2.10.

Table 2.8. St. Louis District Bedding Material Gradation

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

Standard Bedding Material thickness ranges from 8 to12 inches.

Table 2.9. St. Louis District Graded Stone B Gradation

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

Standard thickness for the Graded Stone B gradation ranges from 30 to 42 inches.

Table 2.10. St. Louis District Graded Stone C Gradation [1]

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

[1] 5 percent of the material can weigh more than 400 pounds. No piece shall weigh more than 500 pounds.

Standard thickness for the Graded Stone C gradation ranges from 18 to 24 inches.

2.4.2. Toe Protection. "The undermining of revetment toe protection has been identified as one of the primary mechanisms of riprap revetment failure. In the design of bank protection, estimates of the depth of scour are needed so that the protective layer is placed sufficiently low in the streambed to prevent undermining. The ultimate depth of scour must consider channel degradation as well as natural scour and fill processes. 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.

2.4.3.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 2* T riprap layer is applied.

2.4.4. Side Slopes. Based on guidance provided in EM 1601, riprap section side slopes should not be steeper than 1V on 1.5H. However, a 1V on 2 - 3H is preferred.

2.4.5. Shoreline Key-in. A key-in to the existing shoreline of 5 – 10 feet is recommended for riprap stabilization.

2.4.6. Field Stone. When rounded stone is used instead of angular stone, the D50 calculated for angular stone should be increased by 25%.

2.4.7. Wave Action and Prop Wash. If wave action is a concern, the Hudson Equation, presented in the Shore Protection Manual, should be used to size the rock. 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."

2.4.8. Ice Action. If ice action is expected, rock slopes should be 1V:4H or flatter and/or maximum rock size should be increased to 2*ice thickness (Sodhi).

2.4.9. Underwater Placement. When riprap is placed underwater, the layer thickness should be increased by 50 percent. For example, a 36 inch layer of riprap placed underwater would be increased to a 54 inch layer. However, layer thickness should not be increased by more than 12 – 18 inches.

Additionally, 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.

2.4.10. 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.

2.5. Shoreline Stabilization Technique Design Details

2.5.1. Rock Revetments

2.5.1.1. Design Criteria. Typical rock revetments are shown in photographs 2.5 and 2.6. Currently, 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 inches thick, 1V:1.5 to 3H side slope) 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.

If the area will be subject to ice action, the side slopes should be flattened to at least 1V: 4H.

Photograph 2.5. Rock Revetment Placed on Geotextile

Photograph 2.6. Rock Revetment After Vegetation Growth

2.5.1.2. Lessons Learned. Lessons learned are shown in table 2.11

Table 2.11. Lessons Learned, Rock Revetments

Project	Year Constructed	Lesson Learned
Mud Lake	2005-6	A strip of riprap was placed a few feet above and below the water line. This band of rock was successful in reducing erosion from wave wash and wind fetch erosion.
Lake Chautuaqua	1990s	A strip of riprap was placed a few feet above and below the normal water line. This rock was successful in reducing erosion of wave wash and wind fetch erosion.
Weaver Bottoms	1986	The 30" layer of rock (no filter fabric) placed at a 1V:2H slope on these islands has held up for almost 20 years.
Lake Onalaska	1989	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.
Pool 8, Phase I, Stage I (Horseshoe I)	1989	The 18" layer of rock (w filter fabric) placed at a 1V:3H slope has been stable.
Pool 8, Phase I, Stage II (Boomerang)	1992	The 18" layer of rock (w filter fabric) placed at a 1V:3H slope has been stable.
Pool 8, Phase II	1999	The 18" layer of rock (w filter fabric) placed at a 1V:3H slope has been stable.
Polander Lake, Stage 1	1994	The 32" layer of rock (without filter fabric place at slopes varying from 1V:1.5H to 1V:3H has been stable.
Polander Lake, Stage 2	2000	The 18" layer of rock (w filter fabric) placed at a 1V:3H slope has been stable.
Spring Lake Peninsula	1994	The 18" layer of rock (w filter fabric) placed at a 1V:3H slope has been stable.
Swan Lake	1996	Swan Lake, Year Constructed 1996, An 18" layer of Graded Stone C (400 lb top size), without bedding or geotextile, along exit channel of lower compartment water control structure experiences significant erosion. Bankline soils are silty sands. Problem is remedied in 2002 by redressing side slopes and placing larger gradation rip rap (graded stone B – 1200 lb top size) with average thickness of 42" thickness.
Long Island Division	2001	Long Island Division: Bedding stone was placed under water during high water and high flow conditions following the Flood of 2001 on the Mississippi River. Large quantities of rock were washed away during placement. A larger stone type was chosen to ensure that placement would remain in place.

Table 2.11. Lessons Learned, Rock Revetments

Project	Year Constructed	Lesson Learned
Lake Onalaska	1989	Geotextile filter fabric placed on a 1V:3H slope was easy to install and resulted in an adequate filter.
Pool 8, Phase I, Stage I (Horseshoe I)	1989	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. Contractors tend to meet or exceed design elevations. Based on post-project cross sections, the upper limit of the top elevation range was met or exceeded in almost all cases.
Pool 8, Phase I, Stage II (Boomerang)	1992	Groins were constructed using land-based equipment. Rock was hauled to the site of each groin.
Pool 8, Phase II	1999	Groins were constructed using land-based equipment. Rock was hauled to the site of each groin.
Polander Lake	1994	The Government supplied riprap was stockpiled (this was already done before the project was ever started) in a fairly high pile at Goetz Landing (Fountain City). The Contractor (Brennan) claimed to have an unusually hard time digging into the pile with the front-end loader for two reasons: a) due to the pile being compacted from delivery & stockpiling equipment that had been working on top of the stockpile as the rock was originally stockpiled; and b) due to a fair amount of fine material compacted in with the riprap. Stockpiling also introduces multiple handlings of the riprap, which in turn increases the likelihood of rock size segregation. 2 - The bid item for the rock features was measured by neat line CY. The Contractor claimed a significant amount of overrun on the riprap due to soft foundation conditions in some areas. There are pros and cons as to which payment method is best, CY vs. TN. Payment by the CY favors the Gov't and puts more risk on the Contractor, but the Gov't needs to provide ample borings upfront in the P&S that adequately define the foundation conditions - this equates to more E&D costs. Payment by the TN is less risk to the Contractor, and the Gov't wouldn't need as many borings - the downside of this is that the Contractor may tend to place as much rock as is allowed within the over-tolerance limits since he would get paid for it.

2.5.1.3. Case Studies. Case studies are listed in table 2.12.

Table 2.12. Rock Revetment Case Studies

Site	Rock Slope	T (in)	Height above Normal Pool (feet)	10-YR FL Height (feet)	Geo-textile	Project Length	Year Constructed
Betsey Slough	1V:2.5H	30	4.0	8.5			
Billy's Slough	1V:1.5H	32	3.0	12.0	No		
Dakota	1V:2H	32	2.5	5.0	No		
Dresbach	1V:2H	32	4.5	4.5	No		
Duck Lake Chute	1V:1.5H	32	3.0	8.0	No		
Island 91	1V:2.5H	32	4.0	5.5	No		
Lansing Big Lake	1V:2.5H	36	4.0	8.0	No		
McMillan Island	1V:1.5H to	32	3.0	.0	No		
Minneiska	1V:2H	36	1.0	3.5	o		
Murphy's Cut	1V:3H	30	3.0	6.5	No		
Onalaska Islands	1V:3H	18/27	5.0	4.0	Yes	7370	1989
Polander Lake	1V:1.5H to	32	3 - 5	8.5	No	1120	2000
Pool 8, P1 Boomerang Grassy Horshoe	 1V:3H 1V:3H 1V:3H	 18/27 18/27 18/27	 4.5 2.5 4.5	 4.5 4.5 4.5	 Yes Yes Yes	 780	
Pool 8, Phase 2	1V:3H	18/27	4.5	4.5	Yes		
Richmond Island	1V:2.5H	32	3.5	7.5	No		
Spring Lake	1V:3H	18/27	5.0	4.5	Yes		
Tremp. Daymark	1V:2H	32	4.0	5.5	No		
Willow Island	1V:2.5H	18/27	2.0	7.0	Yes		
Swan Lake							
Stump Lake							
Batchtown							
Calhoun Pt.							
Dresser Island							
Pharrs Island							

2.5.2. Rock Groins

2.5.2.1. Design Criteria. Rock groins, shown in photographs 2.7 and 2.8, are used mainly on new construction in shallow water where wave action and littoral drift are the dominant processes. 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 2.7. Newly Constructed Rock Groin

Photograph 2.8. Rock Groin After a Few Years of Vegetation Growth.

The design criteria presented in this section has been updated according to the lessons learned. 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. Typical design criteria are presented in table 2.13.

Table 2.13. Typical Rock Groin Design Criteria

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

2.5.2.2. Lessons Learned. Lessons learned are shown in table 2.14.

Table 2.14. Lessons Learned, Rock Groins

Project	Year Constructed	Lesson Learned
Weaver Bottoms, Pool 5	1986	Rock groins were built several years after the islands were constructed. These have stabilized the shorelines of Mallard and Swan Island. Some ice damage has occurred to the groins on Swan Island.
Lake Onalaska	1989	Groins were added to the southerly shorelines of these islands several years after the islands were constructed. Severe ice damage has occurred rendering these groins ineffective.
Pool 8, Phase I, Stage II (Boomerang)	1992	The groins place along these shorelines have effectively stabilized over a mile of shoreline.
Spring Lake Peninsula		Very little scalloping occurred along the Spring Lake Peninsula project indicating that groins probably were not needed. Vegetative stabilization alone probably would have stabilized these shorelines.
Trempealeau NWR		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.

2.5.2.3. Case Studies. Case studies are listed in table 2.15.

Table 2.15. Groin Case Studies

Project	Top Width (feet)	Rock Slope	Height Above Normal Pool (feet)	Groin Length (feet)	Groin Spacing (feet)	Length (Feet)	Year
Dresbach Island	3	1V:1.5H	3	30	120		
East Island	3	1V:1.5H	2	30-40	100 & 170		
Grassy Island	2	1V:2H	1.5	30	10 - 150		
Mallard Island	3	1V:1.5H	1.5	30	150		
MN-10	5	1V:2H	2	55	100 - 150		
Onalaska Islands	5	1V:1.5H	2	30	150		
Pool 8 Phase 1	2	1V:2H	1.5	30	180		
Spring Lake	3	1V:1.5H	2	20	100 - 120		
Swan Island	3	1V:1.5H	1.5	30 45	150 - 270 180		
Tremp NWR	3	1V:1.5H	2	30	150		

2.5.3.Rock Vanes

2.5.3.1.Design Criteria. As shown in photograph 2.9 and figure 2.3, rock vanes extend upstream from the shoreline and feature a sloping top elevation. As vanes are overtopped by high water events, they function as weirs and redirect flow away from the shore. Vanes are effective on shoreline adjacent to moving current and the sloping top elevation makes vanes more economical than groins in deeper water.

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 2.3 and 2.4. The plan view of a J-Hook style vane is shown in figure 2.5 and a cross-section of a traditional vane with a root wad is shown in figure 2.6. Typical design criteria are presented in table 2.16.

Photograph 2.9. Rock Vanes at Lost Island Chute

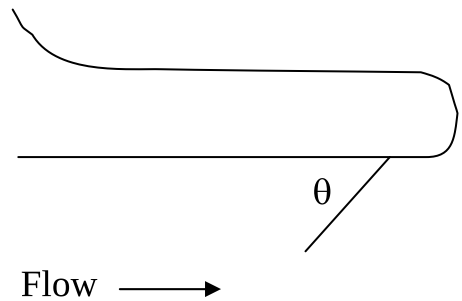

Figure 2.3. Plan View of a Vane Alignment.

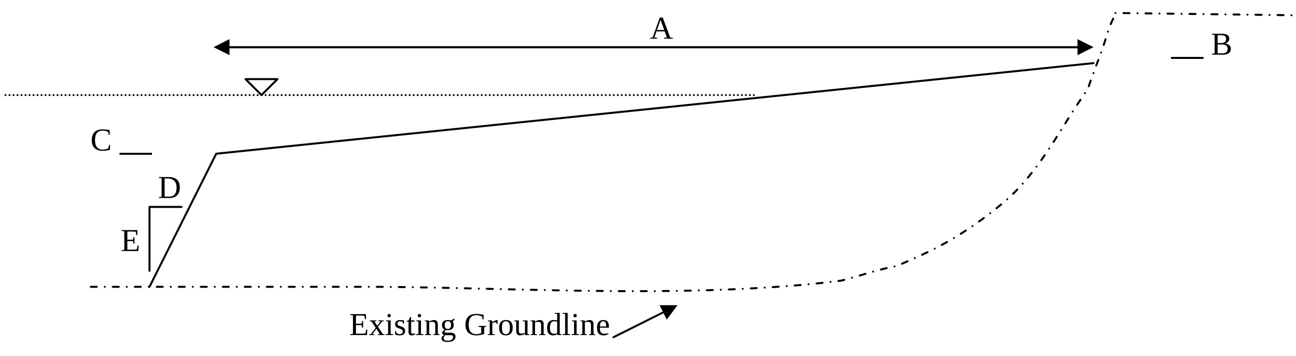

Figure 2.4. Profile View of a Rock Vane

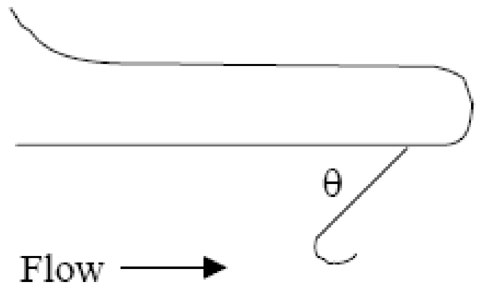

Figure 2.5. Plan View of a J-Hook Vane Alignment

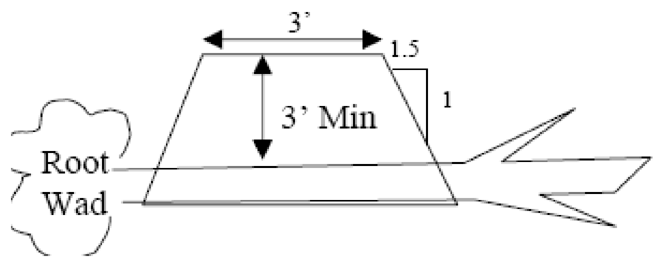

Figure 2.6. Cross-Section of a Tree Built Into a Traditional Vane

Table 2.16. Typical Traditional Vane Design Criteria

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

2.5.3.2. Lessons Learned. Lessons learned are shown in table 2.17.

Table 2.17. Vane Design Lessons Learned

Project	**Lesson Learned**
Lost Island	The vanes appear to have stabilized the shoreline, though some reshaping is still occurring.
Grand Encampment	The vanes appear to have stabilized the shoreline, though some reshaping is still occurring.
West Newton Placement Site	The vanes appear to have stabilized the shoreline, though some reshaping is still occurring.

2.5.3.3. Case Studies. Case studies are as follows:

Lost Island
Grand Encampment
West Newton Placement Site
Spring Lake Islands

2.5.4. Offshore Rock Mounds

2.5.4.1. Design Criteria. Offshore rock mounds 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); 3) shorelines with shallow nearshore bathymetry where it is desirable to get the outside toe of the rock into deeper water to prevent undercutting; and 4) shorelines with heavy wood debris.

Design criteria for offshore rock rounds are presented in table 2.18.

Table 2.18. Typical Offshore Rock Mound Design Criteria

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

2.5.4.2.Lessons Learned. Lessons learned are shown in table 2.19.

Table 2.19. Lessons Learned, Off-shore Rock Mounds

Project	Year Constructed	Lesson Learned
Weaver Bottoms, Pool 5	1986	The elevation of the offshore rock mound constructed on the north side of Swan Island in 1989, decreased in elevation due to settling, ice action, or both. Although the rock mound continued to function adequately, additional rock was placed on portions of this rock mound in 19??.
Peterson Lake, Pool 4		Offshore rock mounds were used to stabilize low elevation islands. These have been stable, though settling has occurred in several reaches.
Polander Lake, Stage 1		An offshore rock mound was constructed to act as breakwater to prevent wave action from impacting a portion of the backwater.
Pool 9 Islands	1994	The Pool 9 Island consists of a rock mound without any earth fill. This structure has been stable, though a few portions of it have settled.
Pool 8, Phase II	1999	An offshore rock mound was retrofitted to this island in a few sections where shoreline erosion was excessive. This rock mound has been stable
Weaver Bottoms, Pool 5	1986	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 five 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.

2.5.4.3. Case Studies. Case studies are listed in table 2.20.

Table 2.20. Case Studies of Offshore Rock Mounds

Project	Rock Back Slope	Top Width	Rock Front Slope	Height Above Normal Pool (feet)	10-yr Flood Height (feet)	Length (Feet)	Year
Billy's Slough	1V:1.5H	5	1V:1.5H	3.0	12.0		
Brice Prairie	1V:1.5H	3	1V:3H	4.0	4.0		
Duck Lake Chute	1V:1.5H	3	1V:1.5H	3.0	8.0		
East Ch.	1V:1.5H	5	1V:1.5H	3.0	11.0		
East I.	1V:1.5H	3	1V:1.5H	3.0	4.5		
Heron I.	1V:1.5H	3	1V:1.5H	3.0	4.5		
Kiep's I.	1V:1.5H	3	1V:2.5H	3.0	6.0		
Mallard I	1V:1.5H	3	1V:1.5H	2.5	4.0		
McMillan Island	1V:1.5H	3	1V:2H	3.0	8.0		
Peterson Lake	1V:1.5H	3	1V:1.5H	2.5	.0		
Pol. LakeBreakwater	1V:1.5H	3	1V:3H	4.5	8.5		
Swan I.	1V:1.5H	3	1V:1.5H	3.0	4.0		
Trapping Island	1V:1.5H	3	1V:1.5H	3.0	4.5		
Tremp. Daymark	1V:1.5H	3	1V:1.5H	4.0	5.5		

2.5.5. 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. Rock log structures are shown in photographs 2.10 and 2.11.

Photograph 2.10. Installation of a Rock Log Structure

Photograph 2.11. Rock-log Structure in Place

2.5.5.1.Design Criteria. The minimum rock cover required to anchor the logs in place is provided in table 2.21.

Table 2.21. Rock Coverage Needed

Structure Type	Minimum Rock Cover Needed (feet) [1]	Typical Bottom Elevation Required and Elevation of Tree Trunk
Rock/Log Island Top Elevation varies	2.0’ if 15’ of tree is covered by rock 1.5’ if 20’ of tree is covered by rock	628.0 to 628.5 = Bottom 630.0 to 630.5 = Tree Trunk

[1] After this analysis 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.

2.5.6. Chevrons. Chevrons are typically used in wider reaches of the river where a flow split is desired. As shown in photographs 2.12 and 2.13, a series of chevrons can be positioned to split flow between a side channel and the main channel. Controlling the flow into the backwater areas helps protect the natural existing bankline. Additionally, eddies created by the structure erode pools on the downstream side of the chevrons. These deep pools provide overwintering habitat for fish.

Photograph 2.12. A Series of Chevrons on the Mississippi River

Photograph 2.13. A Series of Chevrons Aligned To Split Flow Between the Main Channel and a Side Channel, While Protecting the Existing Shoreline

2.5.6.1. Design Criteria. Design Criteria is shown in table 2.22.

Table 2.22. Typical Chevron Design Criteria

Top Width (feet)	varies
Rock Slope	1V:1.5H – 3H
Height above Average Water Surface Elevation (feet)	2+

2.5.6.2. Lessons Learned. Lessons learned are listed in table 2.23.

Table 2.23. Lessons Learned, Chevrons

Lesson Learned
Chevrons work better when used in a series.
Bank revetment is typically needed on the near back of the structures.
Typically build at +2 feet above normal pool

2.5.6.3. Case Studies. Use of Chevrons is relatively new. A Chevron was constructed at Long Island Division in Pool 12 of the Mississippi River.

2.5.7. Berms and Vegetation

2.5.7.1. Design Criteria. One of the primary purposes of the berm is to provide conditions for the growth of woody vegetation, which reduces wave action 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 2.14 shows native prairie grass planted to provide nesting habitat and stabilize the top of the island.

Photograph 2.14 Pool 5, Weaver Bottoms, Swan Island
Native prairie grasses were planted to provide nesting habitat and stabilize the top of the island.

2.5.7.2. Lessons Learned. Lessons learned are shown in table 2.24.

Table 2. 24. Lessons Learned, Berms and Vegetation

Project	**Year Constructed**	**Lesson Learned**
Weaver Bottoms, Pool 5	1986	A low elevation berm placed along the shorelines will naturally colonize with woody vegetation. Berms were not included in the design for these islands and formed accidentally in only a few locations during construction. These berms quickly vegetated, and led to the inclusion of low level berms on future projects.
Lake Onalaska	1989	Islands in deep water have a high rate of erosion. The deep water these islands were placed in (depths greater than 3 feet) resulted in excessive shoreline erosion due to the amount of sand that was transported offshore during the beach building process. Vegetative stabilization is not adequate if the shoreline is exposed to sustained wave and ice action. The berms on these islands continued to erode for several years even though grassy vegetation had established itself on the berm.
Polander Lake, Stage 1		An offshore rock mound was constructed to act as breakwater to prevent wave action from impacting a portion of the backwater.
Pool 9 Islands	1994	The Pool 9 Island consists of a rock mound without any earth fill. This structure has been stable, though a few portions of it have settled.
Pool 8, Phase I Boomerang Island	1992	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.
Pool 8, Phase II	1999	Wind fetches of less than one mile can cause erosion. The berm on the north side of island D2 eroded more than expected during the beach building process. The maximum wind fetch impacting this shoreline was about 4,000 feet.
Polander Lake	2000	The 20- to 40- foot berms were constructed along these islands have been stable.

2.5.7.3. Case Studies. Case studies are listed in table 2.25.

Table 2.25. Vegetation Case Studies

Project	Year Constructed
Weaver Bottoms, Pool 5	1986
Lake Onalaska	1989
Polander Lake, Stage 1	
Pool 9 Islands	1994
Pool 8, Phase I Boomerang Island	1992
Pool 8, Phase II	1999
Polander Lake	2000

2.5.8. Loafing Habitat. Islands and associated shoreline stabilization structures provide loafing habitat for many species. The Fish and Wildlife Work Group (FWWG) established the following parameters for loafing habitat. The FWWG is a group of natural resource managers and biologists established by the River Resources Forum in the St. Paul District, to study fish and wildlife issues in Pools 1 through 10. Another excellent reference on large woody debris structures is Shields, et al. (2004). This reference discusses design procedures, costs, and successes of woody debris structures.

2.5.8.1. Design Criteria for Logs

Height Above Water. Main trunk of the tree should be gently sloped so that with changing water levels there are loafing areas available most of the time and turtles can climb on easily. It would be ideal if the tree had multiple branches so the bottom branches provide fish cover while the upper branches provide loafing areas - even during high water.

- Mixture of elevations is best, due to the different preferences and capabilities of different species and varying water levels. 2” to 12" or more above summer levels is recommended.

- Pelicans, cormorants, eagles, etc, like open areas and 2.3 feet above the water seems to be better than near the surface. Most ducks seem to like structures that are a few inches above the water surface. Herons and egrets will readily perch on logs that are just under the surface to a little above the surface. Turtles, snakes, ducks and some other critters will want logs that are submerged in one area and out of the water in others. This allows them to swim up to the log and easily climb out of the water. The larger birds like pelicans, cormorants & eagles prefer to fly to a branch that is above the surface. The added height helps provide for an easier take-off.

Length. 25 foot minimum length, the longer the better - 60 ft. plus could be used.

Diameter. Trunk diameter of 10 inches or greater would be best. Bigger logs are easier for some wildlife to access at varying water levels and are generally available at more levels. They may persist longer as well. Bigger logs seem to hold up better and appear to attract more water birds. Smaller logs will be more prone to breaking with ice movement. Logs larger than 2' are a lot harder to work with and likely do not attract anything more than a 1' diameter log would.

Tree Species. Trees like black locust will last a lot longer while others like cottonwood might rot faster. A list of tree species in priority order based on resistance to rot, density and possibly other characteristics is discussed in engineering consideration 7 (EC 7). Preliminary list based on longevity – BEST: black locust, white oak WORST: willow, cottonwood, box elder. Other species would fall in between

Location (Sheltered Areas Versus Wind Swept Areas, Backwaters Versus Channels). Areas sheltered from wind-generated waves in both backwaters and along secondary/tertiary channels would be best. Different species of turtles prefer different flow/depth conditions. When basking, most prefer calm winds, small waves and plenty of sun in a low traffic area.

- Most should be located in sheltered backwaters, although if possible some should be placed in flowing channels for riverine turtles, amphibians, birds and other critters. Also, placing some in deeper areas could attract fish.

- Woodducks, teal and some other ducks like secluded quiet backwaters, while mallards seem to like a more wide open area.

Number of Logs Needed for a Structure (Multiple Logs Versus Single Logs). Multiple logs with variable trunk and branch heights at any given location (as described above) would probably be best. Single trees would work too if that is all that is available or doable. Multiple logs do not need to be bundled. Logs grouped together offer more options available at one site, plus multiple logs tend to create a quiet zone around them.

- Ice on the log structures has not been completely addressed. We know that rock holds up reasonably well, but ice damage has occurred at some sites (e.g. rock on Broken Gun island, Brice Prairie barrier island in Pool 7, Trempealeau NWR Pool 6). If the Rosebud Island logs are damaged, we may want to consider putting logs in cover or the inside of a bend where they won't be sticking out for the ice to hook them.

- If anchoring loafing logs within the rock of the groins or mounds, it would be a good idea to fill the rock voids with sand within a radius of 20 feet or so from the trunk/rock interface to avoid luring small creatures to being accidentally trapped in the rock.

- Loafing logs can be anchored into the shoreline of an island by notching the bank, placing the root mass and covering with rock. This technique was used successfully on Indian Slough in Pool 4 and Polander Lake in Pool 5A. Extremely large, spreading root masses might have to be partially trimmed or removed on some species before placement.

2.6. Conclusions

The design criteria presented in the last section essentially represents the conclusions of this document. This criteria was based on four categories of information: 1) desired physical river attributes; 2) habitat parameters; 3) engineering considerations; and 4) and lessons learned. Since the information in these four categories changes due to continued research and experiences, the design criteria can also be expected to change. Habitat project design is an adaptive process, so this handbook will be updated as new information is obtained. These changes will continue to make habitat restoration more efficient and effective.

One thing that is clear is that island construction will continue to be a restoration measure used in the future. Three recent planning efforts, that will undoubtedly form the backbone of future restoration measures, illustrate this

The Habitat Needs Assessment (Theiling et al. 2000) defined the desired form of the river, and created a list of habitat needs, which defined how many acres of various habitat types were needed. Included in this list was the need to create or restore 24,000 acres of island habitat on the UMRS.

The Environmental Pool Plans developed by the Fish & Wildlife Workgroup (2004) identified specific measures that can be implemented in each pool to address systemic goals and objectives presented in the Upper Mississippi River Conservation Committee's report "A Working River and a River that Works" (2001). Many of the measures identified in the Pool Plans involve island construction.

The Upper Mississippi River- Illinois Waterway System Navigation Feasibility Study: Environmental Science Panel Report (2004) contains a synthesis of the objectives from these previous studies along with input from four Navigation Study sponsored stakeholder workshops held in November 2002 (DeHaan et al. 2003). Over a third of the objectives can be linked to island construction.

These recent planning efforts seem to indicate a future that will include island projects. The design criteria, lesson learned, and other information provided in this handbook will improve these efforts.

2.7. References

Anfang, R.A., and G. Wege, 2000. *Summary of Vegetation Changes on Dredged Material and Environmental Management Program Sites in the St. Paul District, Corps of Engineers.*

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.

Fischenich, J. C. (2003). *Effects of Riprap on Riverine and Riparian Ecosystems.* ERDC/EL TR-03-4, U.S. Army Research and Development Center, Vicksburg, MS.

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

River Resources Forum's Fish and Wildlife Work Group. *Environmental Pool Plans, Mississippi River, Pools 1-10 (2004).*

Shields, F.D., N. Morin, and C.M Cooper (2004). *Large Woody Debris Structures for Sand-Bed Channels.* Journal of Hydraulic Engineering, Vol. 130. No. 3.

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.

Theiling C.H., C. Korschgen, H. De Haan, T. Fox, J. Rohweder, and L. Robinson. 2000. *Habitat Needs Assessment for the Upper Misissippi River System: Technical Report.* U. S. Geological Survey, Upper Midwest Environmental Science Center, La Crosse, Wisconsin.

US Army Corps of Engineers, 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.

US Army Corps of Engineers, *EM 1110-2-1204, Engineering and Design - Environmental Engineering for Coastal Shore Protection*, CECW-EH, 10 July 1989.

US Army Engineer Waterways Experiment Station. 1984. *Shore Protection Manual* (SPM), 4th ed.