UMRS-EMP

UPPER MISSISSIPPI RIVER SYSTEM

ENVIRONMENTAL MANAGEMENT PROGRAM

US Army Corps
of Engineers®

ENVIRONMENTAL DESIGN HANDBOOK

August 2006

ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

The Upper Mississippi River System Environmental Management Program (EMP) is successfully implementing innovative and effective habitat projects and conducting cutting-edge monitoring and research. First authorized in Section 1103 of the Water Resources Development Act of 1986, the EMP has made significant contributions to ensure that the Upper Mississippi River System remains a nationally significant ecosystem.

When the EMP began, Habitat Rehabilitation and Enhancement Project (HREP) designers implemented and refined construction techniques in ways not previously imagined. The intent was to improve habitat through site-specific modifications. Since 1986, the Environmental Management Program's HREP component has evolved into a successful program that combines a broad range of construction techniques with approaches that strive to use or mimic natural riverine processes, providing benefits to the river at system, reach, pool and local scales.

Innovations and lessons learned in the HREP program have benefited not only the EMP, but also other programs on the Upper Mississippi River and throughout the United States where similar efforts are underway to preserve and restore habitat on large floodplain river systems. The EMP and the U.S. Army Corps of Engineers are internationally recognized leaders in such endeavors.

There has been significant documentation on individual HREPs, including feasibility level studies, as-built construction drawings, operation and maintenance manuals, and performance evaluation reports. However, these reports have generally been project specific, and often do not describe project lessons learned. It was therefore determined that a design handbook should be created to describe project features common in HREPs. The EMP program covers separate rivers and extends through several U.S. Army Corps of Engineers Districts, which requires some individual attention be paid to new projects. However, there are numerous similarities in the design of these project features that the design process can be summarized in this document. Each chapter has been prepared by several different individuals, but in general the design methodology, case studies, lessons learned, and references are included in each chapter.

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INTRODUCTION

1.1. Environmental Management Program

The Upper Mississippi River System Environmental Management Program (EMP) is successfully implementing innovative and effective habitat projects and conducting cutting-edge monitoring and research. First authorized in Section 1103 of the Water Resources Development Act of 1986, the EMP has made significant contributions to ensure that the Upper Mississippi River System remains a nationally significant ecosystem. The Upper Mississippi River System is shown in figure 1.1.

Figure 1.1. Upper Mississippi River Basin

1.2. Habitat Rehabilitation and Enhancement Projects

Fish and wildlife on the Upper Mississippi River System has been declining in quantity, quality and habitat diversity for decades. Much of this decline is associated with human activity throughout the basin, including upland land use and development, floodplain farming and development, and changes brought about by the system's 9-foot channel navigation project. While the decline is caused by a variety of factors, some of which the EMP cannot address, Habitat Rehabilitation and Enhancement Projects (HREPs) are seeking to modify the river's floodplain structure and hydrology to counteract the effects of an aging impounded river system. For example, HREPs may alter sediment transport and deposition, water levels, or the connections between the river and its floodplain. These types of physical changes subsequently affect water quality parameters such as temperature, dissolved oxygen, and distribution of suspended sediments, thereby ultimately improving fish and wildlife habitat. The EMP restoration planning approach and techniques have served both nationally and internationally as models for other river restoration planners. Individual HREP locations are shown in figure 1.2.

1.3. HREP Impacts

When the EMP began, HREP designers implemented and refined construction techniques in ways not previously imagined. The intent was to improve habitat through site-specific modifications. Since 1986, the HREP component has evolved into a successful program that combines a broad range of construction techniques with approaches that strive to use or mimic natural riverine processes, providing benefits to the river at system, reach, pool and local scales. In 2006, the EMP had provided more that $145,508 for 86 projects which had been completed or implemented since 1987. Over 146,000 acres are expected to be impacted with completed and proposed projects (according to 2006 information). As of 2004, the EMP had completed 40 HREPS, improving fish and wildlife habitat on almost 67,000 acres. Another 8 HREPs were under construction and 16 projects were in various stages of design. These additional 24 projects are expected to improve approximately 74,000 acres of additional habitat. A summary of these projects, as of July 2006, is shown in figure 1.3.

1.4. HREP Feature Components

To accomplish their habitat management and restoration objectives, HREPs employ a variety of techniques including: island creation, shoreline protection, water level management, backwater dredging, river training structures, secondary channel modification, aeration, floodplain restoration, reforestation and vegetation, and tributary restoration. Many projects combine these features to address more complex problems. The range of techniques that have been used, or are being considered for possible future use is extensive, and is shown in table 1.1. A list of project features at each project site is shown in table 1.2 .

1.5. HREP Documentation

There has been significant documentation on individual HREPS, including feasibility level studies known as Definite Project Reports, as-built construction drawings, operation and maintenance manuals, and performance evaluation reports. However, these reports have generally been project specific, and often do not describe project lessons learned. Several of these documents are available electronically on the internet at the EMP web page: http://www.mvr.usace.army.mil/EMP/default.htm

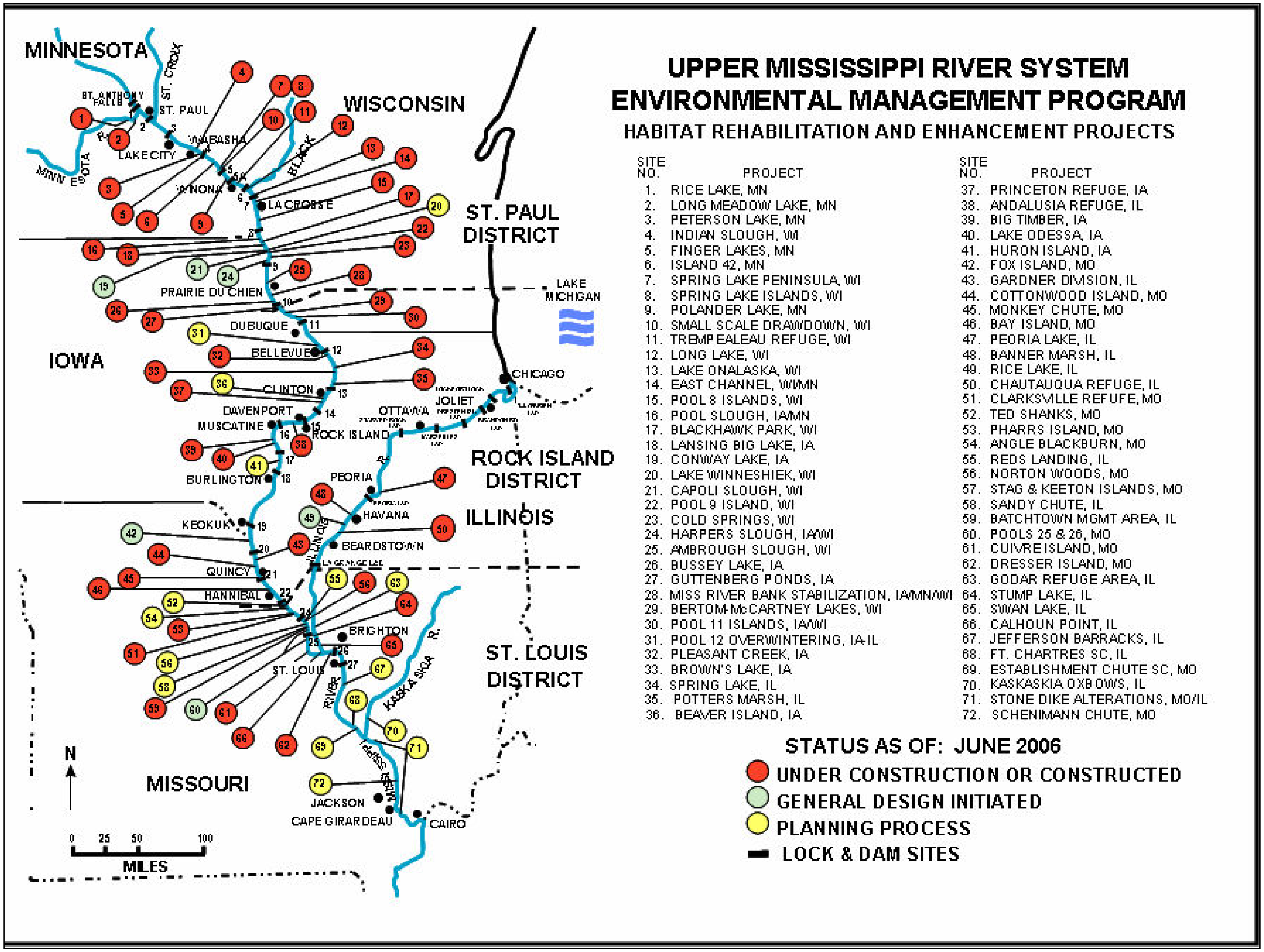

Figure 1.2. Habitat Rehabilitation and Enhancement Projects

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Summary of EMP Projects

The Environmental Management Program has provided more **$145,508,517** in funding for **86** Habitat Restoration and Enhancement projects since **1987**.

Number of Restoration Projects by Legislative District

IA-01 - 7	IA-02 - 3	IA-04 - 4	IL-12 - 6	IL-16 - 3
IL-17 - 13	IL-18 - 4	MN-01 - 5	MN-02 - 1	MN-03 - 1
MO-02 - 7	MO-03 - 1	MO-08 - 3	MO-09 - 11	WI-03 - 17

EMP Project Results

Restoration Features

Feature	Number of Projects
Backwater Dredging	31
Water Level Management	43
Islands	15
Bank Stabilization	16
Side Channel Restoration	42
Water Aeration	5
Moist Soil Management Unit	22
Reforestation/Revegetation	23
Other (i.e. Access Road)	22

Acres Affected

Stage	Number of Projects	Acreage
Proposed	30	19,760
Initiated	16	50,528
Complete	40	76,645
Total	**86**	**146,933**

Habitat Benefits

Type	Acreage
Main Channel Habitat	
Secondary Channel Habitat	
Contiguous Backwater	
Isolated Backwater Habitat	
Island Habitat	

ILLINOIS DEPARTMENT OF NATURAL RESOURCES · DNR · NRCS Natural Resources Conservation Service · U.S. FISH & WILDLIFE SERVICE · Minnesota DEPARTMENT OF NATURAL RESOURCES · WISCONSIN DEPT. OF NATURAL RESOURCES · The Nature Conservancy

Figure 1.3. Summary of EMP Projects (July 2006)

Table 1.1. EMP HREP Features

Technique	Objectives
Dredge backwaters	Alter flow patterns and velocity Improve floodplain structural diversity Increase deep water fish habitat for overwintering Provide access for fish movements Provide dredged material to support revegetation and island building
Water Level Management	Restore natural hydrologic cycles Promote growth of aquatic plants as food for waterfowl Consolidate bottom sediments Control rough fish
Island Creation	Decrease wind and wave action Alter flow patterns and sediment transport Improve aquatic plant growth Improve floodplain structural diversity Provide nesting and loafing habitat for waterfowl and turtles Restore woody vegetation
Shoreline Stabilization	Prevent shoreline erosion Maintain floodplain structural diversity Create fish habitat Reduce sediment loads to backwaters Create barriers to waves and currents
Secondary Channel Modification	Improve fish habitat and water quality by altering inflows Stabilize eroding channel Reduce sediment load to backwaters by reducing flow velocities Maintain water temperature and provide rock substrate
Water aeration	Improve fish habitat and water quality by introducing oxygenated water
Miscellaneous Experimental and Complementary Techniques	
Seed islands	Isolated wetlands
Upland sediment control	Weirs
Land Acquisition	Rock sills
Riffle pools	Sediment traps
Potholes	Mussel substrates
Notched wing dams	Bottomland forest restoration
Anchor tree clumps	Vegetative plantings

Table 1.2. HREP Feature Components

Project Name	Status	Acres Affected	Backwater Dredging	Water Level Management	Islands	Bank Stabilization	Side Channel Restoration & Enhancement	Aeration	MSMU	Reforestation & Revegetation	Other
Alton Pool Side Channels	Proposed	0.00					X				
Ambrough Slough	Complete	2,500.00	X	X			X	X			
Andalusia	Complete	393.00		X	X		X				X
Angle Blackburn Islands	Proposed	500.00	X				X		X		
Baldwin Backwater Protection	Proposed	0.00	X	X			X				
Bank Stabilization	Complete	1,500.00		X		X	X				
Banner Marsh	Complete	5,524.00		X						X	X
Batchtown	Initiated	3,300.00					X		X		
Bay Island	Complete	650.00		X					X	X	X
Beaver Island	Proposed	0.00									
Bertom Mccartney Lakes	Complete	2,000.00	X	X							X
Big Timber	Complete	1,039.00	X	X						X	
Blackhawk Park	Complete	282.00					X				X
Brown's Lake	Complete	453.00	X	X			X			X	
Bussey Lake	Complete	213.00	X	X							
Calhoun Point	Initiated	2,300.00	X						X		
Capoli Slough	Initiated	600.00	X		X	X					
Clarence Cannon	Proposed	3,750.00	X	X		X				X	
Clarksville Refuge	Complete	325.00							X		
Cold Springs	Complete	35.00					X				
Conway Lake	Initiated	560.00	X	X	X			X			
Cottonwood Island	Complete	463.00	X				X			X	X
Cuivre Island	Complete	1,400.00		X			X				X
Dresser Island	Complete	940.00		X							
East Channel	Complete	70.00				X					
Establishment Chute	Proposed	0.00					X		X		
Finger Lakes	Complete	264.00		X							
Fox Island	Proposed	2,100.00		X						X	
Ft Chartres Side Channel	Proposed	100.00		X			X				X

Table 1.3. HREP Feature Components

Project Name	Status	Acres Affected	Backwater Dredging	Water Level Management	Islands	Bank Stabilization	Side Channel Restoration & Enhancement	Aeration	MSMU	Reforestation & Revegetation	Other
Glades Wetlands	Proposed	300.00	X	X					X		X
Godar Refuge	Proposed	300.00							X		
Guttenberg Waterfowl Ponds	Complete	50.00		X							X
Harpers Slough	Initiated	2,200.00			X	X					
Huron Island	Proposed	0.00									
Indian Slough	Complete	631.00	X	X			X				X
Island 42	Complete	95.00	X				X	X			
Jefferson Barracks	Proposed	0.00		X			X				X
Kaskaskia River Oxbows	Proposed	200.00		X			X				
Lake Chautauqua	Complete	4,200.00		X		X	X				X
Lake Odessa	Initiated	6,788.00	X	X			X		X	X	
Lake Onalaska	Complete	7,000.00			X	X	X	X			
Lake Winneshiek	Proposed	6,000.00	X		X						
Lansing Big Lake	Complete	9,755.00		X		X					
Least Tern	Proposed	0.00				X					X
Long Island (Gardner) Division	Initiated	6,000.00	X	X		X	X			X	
Long Lake	Complete	40.00		X			X				
Long Meadow Lake	Initiated	1,000.00		X						X	
Monkey Chute	Complete	88.00	X								
Norton Woods	Proposed	0.00	X							X	
Osborne Side Channel	Proposed	0.00					X				
Peoria Lake	Complete	14,000.00		X	X		X		X	X	
Peterson Lake	Complete	500.00		X		X	X				
Pharrs Island	Complete	600.00				X	X		X		X
Piasa - Eagle's Nest Islands	Proposed	0.00					X				
Pleasant Creek	Complete	2,350.00							X	X	
Polander Lake	Complete	1,000.00	X	X	X	X				X	

Table 1.4. HREP Feature Components

Project Name	Status	Acres Affected	Backwater Dredging	Water Level Management	Islands	Bank Stabilization	Side Channel Restoration & Enhancement	Aeration	MSMU	Reforestation & Revegetation	Other
Pool 11 Islands	Initiated	10,342.00	X		X		X	X			
Pool 12 Overwintering	Initiated	6,900.00	X							X	
Pool 24 Islands	Proposed	0.00	X	X			X		X	X	
Pool 25 Island	Proposed	200.00	X		X	X				X	
Pool 8 Islands Phase I	Initiated	1,000.00			X						
Pool 9 Islands	Complete	320.00			X						
Pool Slough	Initiated	65.00							X		
Pools 25 And 26	Proposed	3,185.00	X	X	X					X	
Potters Marsh	Complete	2,305.00	X	X			X				X
Princeton Refuge	Complete	1,129.00		X					X		
Red's Landing Wetlands	Proposed	0.00		X			X			X	
Rice Lake	Initiated	5,600.00					X		X	X	X
Rice Lake - Minnesota	Complete	210.00					X			X	
Rip Rap Landing	Proposed	200.00		X			X				
Sandy Chute	Proposed	200.00		X			X				
Schenimann Chute	Initiated	273.00		X			X				X
Small Scale Drawdown	Complete	52.00								X	
Smith Creek	Proposed	650.00					X		X		
Spring Lake	Initiated	3,300.00							X		X
Spring Lake Islands	Initiated	300.00	X		X						
Spring Lake Peninsula	Complete	300.00	X	X		X					
Stag Islands	Complete	469.00				X					
Stone Dike Alterations	Proposed	0.00									X
Stump Lake	Complete	2,958.00					X		X		
Swan Lake	Complete	4,922.00	X	X			X		X		
Ted Shanks	Proposed	2,000.00		X			X		X	X	X
Trempeleau	Complete	5,620.00							X		
Turner Island And Chute	Proposed	75.00	X	X							
West Alton Tract	Proposed	0.00			X		X				X
Wilkinson Island	Proposed	0.00									

1.6. EMP Database

A database for HREP projects was developed in the 1990s. This database was revised in 2005 and 2006 to a Microsoft Access database. The purpose of the database is to compile important information at each HREP site and allow the information to be shared and used for future projects. Output tables for the database can range from project specific fact sheets to program analysis of various feature impacts. The database is integrated with GIS data to allow for various query options. It is anticipated that the database, used in coordination with this handbook, will allow for more thorough and streamlined planning of future HREPs.

1.7. Report Format

It was determined that a design handbook should be created to describe project features common in HREPs. The EMP program covers separate rivers and extends through several U.S. Army Corps of Engineers Districts, which requires some site specific attention be paid to new projects. However, there are numerous similarities in the design of these project features that the design process can be summarized in this document. Each chapter has been prepared by several different individuals, but in general the design methodology, case studies, lessons learned, and references are included in each chapter, which are as follows: Shoreline Stabilization; Localized Water Level Management; Dredging; River Training Structures and Secondary Channel Modifications; Aeration; Floodplain Restoration; Tributary Restoration; and Islands.

1.8. Report Preparation

This document addresses techniques currently being used on the Upper Mississippi River System, or proposed for future projects. The handbook primarily addresses the physical characteristics of the process. Future work will focus on biological characteristics and will continue to incorporate lessons learned from both new and aging HREPs.

Work on this handbook was initiated in 2004. A multi-district team was created, and the handbook format was discussed in great detail during and EMP HREP Design Meeting in January 2005, held at the U.S. Army Corps of Engineers, Rock Island District Office. The recommended format was presented to the EMP Coordinating Committee (EMPCC) during their quarterly meetings. The EMPCC approved the final format. Primary authors were identified for each chapter and draft chapters were prepared by May 2005. The chapters were distributed to each district for reviews and to include their own district's information. All information was incorporated and an official draft report was completed in July 2005. In August 2005, the document was discussed at the EMP Workshop, held in Davenport, IA. Comments were received during this workshop. An invitation for comments was sent out to the EMPCC, service agencies, Corps employees, and others interested in the document. Comments were due by January 2006, however, due to emergency deployments by several individuals (in response to Hurricane Katrina, and the War in Iraq), the comment period was extended to May 2006. The comments were incorporated by the primary authors, and the final chapters were completed in July 2006.

SHORELINE STABILIZATION

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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.

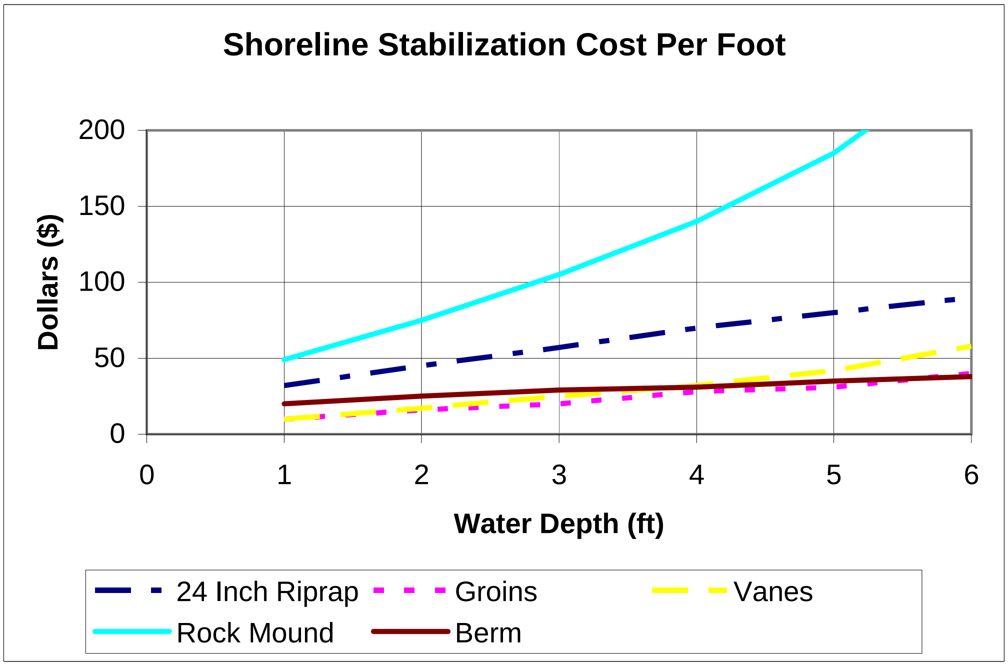

Figure 2.1. Rock Based Shoreline Stabilization Costs Per Foot of Shoreline (MVP Cost Data)

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).

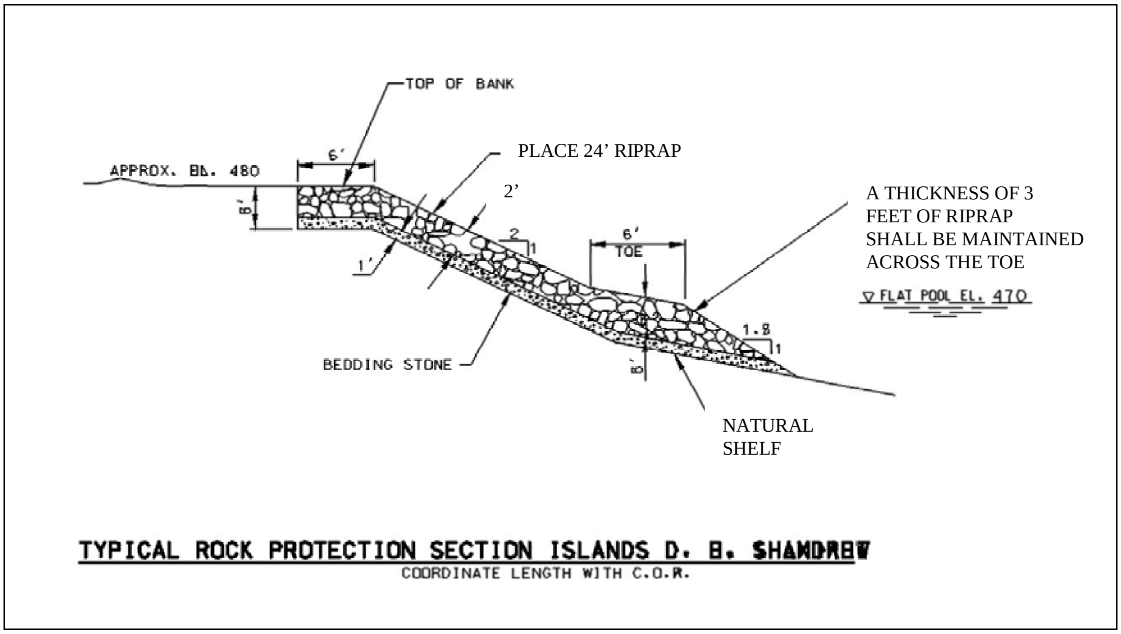

Figure 2.2. Typical Rock Protection Section

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	1V:3H	18/27	4.5	4.5	Yes		
Grassy	1V:3H	18/27	2.5	4.5	Yes		
Horshoe	1V:3H	18/27	4.5	4.5	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

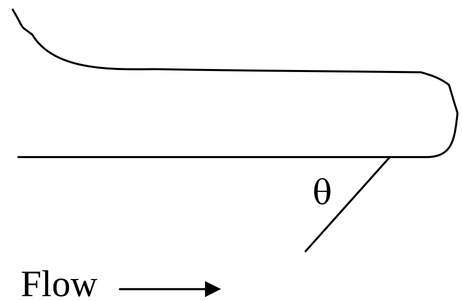

Figure 2.3. Plan View of a Vane Alignment.

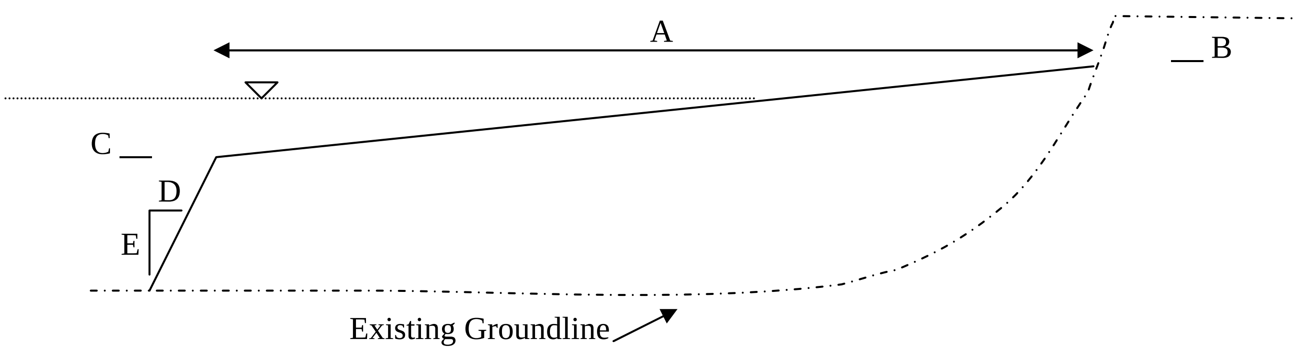

Figure 2.4. Profile View of a Rock Vane

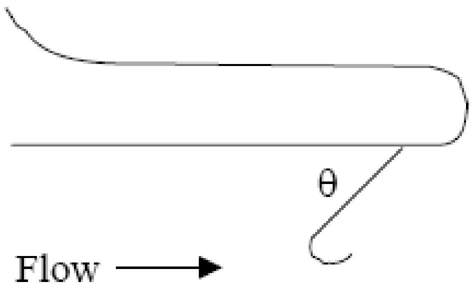

Figure 2.5. Plan View of a J-Hook Vane Alignment

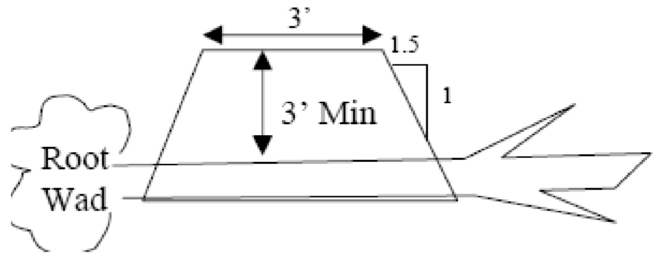

Figure 2.6. Cross-Section of a Tree Built Into a Traditional Vane

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.

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LOCALIZED WATER LEVEL MANAGEMENT

CHAPTER 3

UPPER MISSISSIPPI RIVER SYSTEM
ENVIRONMENTAL DESIGN HANDBOOK

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LOCALIZED WATER LEVEL MANAGEMENT

3.1 Resource Problem

Large river ecosystems such as the UMRS are characterized by seasonal cycles of flood and drought (or low flow). A variety of ecological functions and processes are linked to this cycle. Development of water resources for hydropower or navigation typically alters and disrupts these natural cycles. Fortunately in the UMRS, the flood stage of the hydrograph is relatively unaltered, but low stages have been eliminated to support commercial navigation.

Much of the flora and fauna native to the Upper Mississippi River region is adapted to the wide variations in water level that characterized the river and its floodplain prior to establishment of the lock and dam system. Since the implementation of the 9-Foot Channel Project, however, these variations have been truncated and the low river stage portion of the hydrograph has been increased to support commercial navigation. This water level control, coupled with other cumulative effects, has degraded ecosystem conditions, mainly the loss of backwater depth and aquatic plants in many areas.

Numerous (twenty seven as of 2005) EMP habitat projects have attempted to recreate this variability in specific areas to benefit such species. Several responses to water level management projects have been demonstrated since the 1997 Report to Congress. For example, Lake Chautauqua on the Illinois River near Havana, Illinois has been managed as a National Wildlife Refuge since 1936, but wetland management capabilities and habitat quality had degraded over the years. Improved water level management capabilities in the southern pool completed in 1999 resulted in phenomenal wetland plant response, which, in turn, was met with the highest waterfowl use since the 1970s. Submersed aquatic vegetation and marsh plants colonized almost 1,400 acres after project completion. Fish response monitoring indicates the site can produce and export hundreds of millions of larval fish to the Illinois River.

Water level management projects that include levees, pumps, and control structures are more costly to build, maintain, and operate relative to other types of Habitat Rehabilitation and Enhancement Projects (HREPs). Recent evaluations of habitat objectives and opportunities through pool planning and the Upper Mississippi River-Illinois Waterway Navigation Feasibility Study are revealing; however, that water level management may be the only reliable mechanism in some instances to counteract the impacts of impoundment and floodplain development and thus achieve the desired habitat conditions. Evidence from EMP and other water level management projects indicates these projects can be effectively operated for multiple management objectives, including waterfowl, shorebirds, wading birds, reptiles, amphibians, and fisheries. Connectivity with main stem habitats will be a focus of future project investigations. Water control structures that can also permit fish movement are being designed and tested.

Water level management features are named differently depending on the type of habitat improvements and other considerations. For the purpose of this report, they are divided into three categories, moist soil management units, backwater lakes, and green tree reservoirs. The features which can control water levels will apply regardless of which name is chosen for the habitat.

3.2 Moist Soil Management Units

Generally, the goal of a moist-soil management unit (MSMU) is wetland habitat enhancement with the objective of providing suitable habitat for waterfowl. MSMUs are typically managed to include annual draw-downs. This technique is well accepted for wetland management and has been considered necessary for rejuvenating older, unproductive impoundments (Kadlec 1962). Stabilizing water levels, particularly at high levels, can be detrimental; and periodic drying and flooding is beneficial for establishment of desired aquatic vegetation (Weller 1978, 1981:70). The need for seasonal instability should not be equated with erratic water level changes at any time of the year (Weller 1981:70). Wildlife productivity will likely increase as wetlands experience a regular flooding cycle (Mitsch and Gosselink 1986:430).

The basic operating plan for a MSMU is to keep water out in the late spring and summer and to gradually flood the area in the fall. In a multiple cell system, it is best to be able to control water levels independently. One way to accomplish this independent filling is to have the pump discharge into a water control structure along the cross dike. This structure would be designed to have structures at both ends to control flow to either cell. A gate structure would be installed within each cell to allow independent gravity drainage. Table 3.1 represents a typical annual management plan for a MSMU.

Table 3.1. Typical MSMU Annual Management Plan

Month	Action	Purpose
April to July	Dewater area	Expose and maintain mudflats to allow vegetation
Aug to Nov	Gradually increase water levels to correspond with growth of marsh plant community	Provide access to food plants for migratory waterfowl
Dec to April	Maintain water levels to maximum extent possible and then release water late during early spring	Maintain winter furbearer habitat and then prepare for aquatic plant germination through gradual water release

MSMUs are typically designed to include water containment, water supply, and water control structures. Water containment is provided by construction of perimeter levees, cross dikes, and overflow spillways; which are used to impound water during seasonal waterfowl migrations or keep water out of the impounded area. Water supply may be provided by either river water or ground water through the use of a pump station or well, respectively. Water control structures are utilized to maintain desired water elevations throughout the year. There are many types of water control structures such as stoplog, gatewell, overflow weir, and fuse plug. The water control structures typically used for HREP projects include stoplogs, gatewells or other measures.

MSMUs are part of the HREPs listed in table 3.2.

Table 3.2. HREPS Which Include Moist Soil Management Units

Andalusia Refuge HREP, Pool 16, Upper Mississippi River Miles 462.0 - 463.0, Rock Island County, Illinois, CEMVR
Batchtown HREP, Pool 25, Upper Mississippi River Miles 242.5 - 246.0, Calhoun County, Illinois, CEMVS
Bay Island HREP, Pool 22, Upper Mississippi River Miles 311.0 - 312.0, Marion County, Missouri, CEMVR
Calhoun Point HREP, Pool 26, Upper Mississippi River Miles 221.0 – 221.0, Calhoun County, Illinois, CEMVS
Clarksville Refuge HREP, Pool 24, Upper Mississippi River Miles 275.0 – 275.0, Pike County, Missouri, CEMVS
Dresser Island HREP, Pool 26, Upper Mississippi River Miles 206.0 – 209.0, St. Charles County, Missouri, CEMVS
Guttenberg Waterfowl Ponds HREP, Pool 11, Upper Mississippi River Miles 614.0 - 615.0, Grant County, Wisconsin, CEMVP
Pleasant Creek HREP, Pool 13, Upper Mississippi River Miles 548.7 - 552.8, Jackson County, Iowa, CEMVR
Pool Slough HREP, Pool 9, Upper Mississippi River Miles 673.0 - 673.0, Allamakee County, Iowa CEMVP
Potters Marsh HREP, Pool 13, Upper Mississippi River Miles 522.5 - 526.0, Carroll and Whiteside Counties, Illinois, CEMVR
Princeton Refuge HREP, Pool 14, Upper Mississippi River Miles 504.0 - 506.4, Scott County, Iowa, CEMVR
Rice Lake HREP, LaGrange Pool, Illinois Waterway River Miles 132.0-138.0, Fulton County, Illinois, CEMVR
Spring Lake HREP, Pool 13, Upper Mississippi River Miles 532.5 - 536.0, Carroll County, Illinois, CEMVR
Stump Lake HREP, Alton Pool, Illinois Waterway River Miles 7.2 – 12.7, Jersey County, Illinois, CEMVS
Swan Lake HREP, Alton Pool, Illinois Waterway River Miles 5.0 – 13.0, Calhoun County, Illinois, CEMVS

3.3 Backwater Lake with Water Level Control

Prior to construction of the navigation system, water levels typically dropped during the summer months allowing backwater lakes to consolidate. This drying effect encouraged emergent aquatic plants, such as bulrush and arrowhead to grow. With the more stable water levels created by the navigation pools, this low-water effect and drying of sediments no longer occurs. Plant beds that depend on this drying process have decreased in extent or disappeared entirely. Stands of perennial emergent aquatic plants are important to fish and wildlife populations because they provide food, shelter, and dissolved oxygen. Hence, a backwater lake with water level control may be implemented to help improve conditions for the growth of aquatic vegetation.

Generally, the goal of a backwater lake with water level control is aquatic habitat restoration with the objective of providing suitable habitat for waterfowl and fisheries. Water level control of a backwater lake consists of a temporary seasonal increase or decrease in water elevations to mimic natural hydrologic regimes in order to improve large areas of shallow aquatic habitat.

Similar to MSMUs, backwater lakes with water level control are typically designed to include water containment, water supply, and water control structures. These are similar to those described for MSMUs. Backwater lakes with water level control are listed in Table .

Table 3.3. Backwater Lakes with Water Level Control

Batchtown HREP, Pool 25, Upper Mississippi River Miles 242.5 - 246.0, Calhoun County, Illinois, CEMVS
Banner Marsh HREP, LaGrange Pool, Illinois Waterway River Miles 138.0 - 144.0, Fulton and Peoria Counties, Illinois, CEMVR
Calhoun Point HREP, Pool 26, Upper Mississippi River Miles 221.0 – 221.0, Calhoun County, Illinois, CEMVS
Clarksville Refuge HREP, Pool 24, Upper Mississippi River Miles 275.0 – 275.0, Pike County, Missouri, CEMVS
Lake Chautauqua HREP, LaGrange Pool, Illinois Waterway River Miles 124.0 - 129.5, Mason County, Illinois, CEMVR
Lake Odessa HREP, Pools 17-18, Upper Mississippi River Miles 435.0 - 440.0, Louisa County, Iowa, CEMVR
Peoria Lake HREP, Peoria Pool, Illinois Waterway River Miles 162.0 - 181.0, Peoria and Woodford Counties, Illinois, CEMVR
Rice Lake HREP, Minnesota River Miles 15.0 – 17.5, Scott and Hennepin Counties, Minnesota, CEMVP
Small Scale Drawdown HREP, Pool 5, Upper Mississippi River Miles 746.0 – 746.0, Buffalo County, Wisconsin, CEMVP
Stump Lake HREP, Alton Pool, Illinois Waterway River Miles 7.2 – 12.7, Jersey County, Illinois, CEMVS
Swan Lake HREP, Alton Pool, Illinois Waterway River Miles 5.0 – 13.0, Calhoun County, Illinois, CEMVS
Trempealeau National Wildlife Refuge HREP, Pool 6, Upper Mississippi River Miles 718.0 – 724.0, Trempealeau County, Wisconsin, CEMVP

3.4 Green Tree Reservoirs

3.4.1. Design Methodology and Criteria . A green tree reservoir (GTR) is a forested bottomland that is temporarily flooded throughout the winter months to attract ducks, mainly mallard and wood ducks. The availability of flooded bottomland hardwood timber during the winter months is critical to the breeding success of the mallard duck. A GTR is designed to hold water while trees are dormant. This prevents permanent tree damage and possible death; hence, the name “green tree” reservoir.

GTRs enhance waterfowl habitat by providing reliable resting and feeding areas during the fall and winter months. The flooding of bottomland hardwoods to a depth of 1 to 18 inches provides ducks access to fallen acorns and other seeds.

General design criteria for a GTR include (1) a dominance of bottomland hardwood oaks, gums, and ashes at least 40 years old, (2) a minimum of 10 acres in order to attract ducks on a regular basis, (3) an area that is relatively flat to maximize the flooded acreage with a depth of 1 to 18 inches (otherwise the trees in low locations will be flooded too long and eventually die), (4) soils with good water holding capabilities, (5) an adequate water supply, (6) a close proximity to traditional waterfowl wintering grounds and flight paths, and (7) the water table must be at least 3 feet deep (totally saturated soil) during the growing season to reduce root pruning. If root pruning occurs, the tree will develop a swelled butt, have stem tip dieback, and produce few acorns. Soil moisture conditions during the growing season must be dry enough for regeneration to occur. Regeneration is the key for future GTRs.

Preferred mast trees (oaks) for a GTR must have a small acorn (fruit/seed) that can be easily consumed by waterfowl (e.g. Pin, Overcup, Nuttall, Swamp White, and native small seeded Pecan). Other preferred mast trees will depend on the project location. Ash, elm, and maple are not good mast producers in the fall, but their winged seeds are valuable and are consumed by ducks during the late winter when other mast producers are scarce.

Most GTRs are created by the construction of perimeter levees and the installation of water control structures. When necessary, pump stations or wells are also constructed to provide an adequate water supply.

There are several construction considerations when designing a perimeter levee for a GTR. The topography of the site should be surveyed. The perimeter levee should be located to flood the maximum number of hardwood trees to a depth of 1 to 18 inches. Where possible, existing roads, natural ridges, etc. should be utilized as part of the perimeter levee to lower costs. In some cases, it may be necessary for the water depth at the lower end to be greater than a couple feet to increase the water surface acreage at the upper end of the GTR. The location of the GTR should be easily accessible by vehicle for construction and O&M. The top width of the perimeter levee should be a minimum of 10 feet to accommodate vehicular access. The height of the perimeter levee should include a minimum of two feet of freeboard from the maximum water depth. An overflow spillway is typically incorporated within the perimeter levee. The side slopes of the perimeter levee and overflow spillway should be gradual to reduce erosion damage from overtopping events. The perimeter levee should be seeded with perennial grass following construction.

When designing water control structures for a GTR, the capacity of these structures is critical. Flood events that inundate the GTR during the growing season (early spring to late fall) need to be removed as quickly as possible. Flooding during the growing season can cause stress and ultimately tree mortality if not removed within a few days.

The design of a pump station or well for a GTR would be similar to that for a MSMU.

GTRs have a basic operating plan. They are flooded in the late fall and dewatered in the early spring. However, to ensure that the habitat provided by a GTR is available throughout the project life, site managers should implement the following techniques.

Flooding and dewatering dates should vary. The GTR should not be flooded before the leaves begin to turn color in the fall and should be dewatered before new leaves appear in the spring. Vary the dates of flooding in the fall up to one month and dewatering in the spring up to three months. Continue this over a several year period. Leave the GTR unflooded one out of every six to eight years.

Flooding depths should vary from year to year and even within the same season. The preferred feeding depth of many ducks is less than six inches. Partial dewatering can produce “puddles” where invertebrates concentrate, which provide an important food source.

Flood and dewater slowly. Flooding the GTR slowly provides optimum habitat conditions over an extended time period. The dewatering rate should be less than one inch per day. Otherwise, the nutrients associated with leaf decomposition that promote invertebrates and good timber vigor may be flushed away.

Timber management can improve the habitat benefits for ducks by adjusting the species composition and density of the mast trees present. This can be accomplished by selectively harvesting or killing single trees or groups of trees. The reasons for conducting timber management include the following; (1) to optimize mast production, especially those trees with a d.b.h. of greater than 14 inches, by maintaining approximately 80 square feet basal area of desirable species, (2) to maintain a variety of mast producers since no single species will produce suitable quantities of mast every year, (3) to remove less desirable trees to make room for better mast producers, and (4) to create snags that may function as suitable habitat for nesting by wood ducks and other wildlife.

General maintenance of a GTR includes periodic mowing of the perimeter levee to suppress undesirable growth, inspection of the water control structures to ensure they are functioning properly, and controlling rodent damage on the perimeter levee.

3.4.2. Lessons Learned. No lessons learned have been reported.

3.4.3. References

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EM 1110-2-3104, Engineering and Design - Structural and Architectural Design of Pumping Stations, CECW-ED, 30 June 1989, http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-3104/toc.htm

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Hayes, D. F.; Olin, T. J.; Fischenich, J. C.; and Palermo, M. R. (2000). *Wetlands Engineering Handbook*, ERDC/EL TR-WRP-RE-21, U. S. Army Engineer Research and Development Center, Vicksburg. View on-line or download Part1.

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3.4.4. Case Studies.

Case studies are listed in table 3.4.

Table 3.4. Green Tree Reservoirs

Calhoun Point HREP, Pool 26, Upper Mississippi River Miles 221.0 – 221.0, Calhoun County, Illinois, CEMVS
Cuivre Island HREP, Pool 26, Upper Mississippi River Miles 233.0 – 239.0, Lincoln and St. Charles Counties, Missouri, CEMVS

3.5. Design Features Common for Water Level Management

Water level management projects have several similar design features important to the proper operation and maintenance of these systems. These features are described in the following sections.

3.5.1. Perimeter Levees, Cross Dikes, and Overflow Spillways

3.5.1.1. Design Methodology and Criteria. Some general design criteria for this project feature are to 1) construct a reliable levee system that provides adequate flood protection to meet the sponsor's seasonal and/or annual management goals and 2) locate borrow sites in areas that improve the suitable habitat for migratory birds.

Level of Protection. When designing a perimeter levee, it is crucial to prevent interior sedimentation and to provide protection against loss of water control due to flooding. Therefore, the level of protection provided by the levee system needs to be adequate. When determining the level of protection needed for the levee system, consider various flood elevations (2- year, 5-year, 10-year, 15-year, 20-year, 25-year, etc.) and determine how many times each flood elevation has been exceeded based on the data available. Then evaluate the additional cost of raising the levee to a higher levee of protection versus the decrease in the exceedance rate. The approximate level of protection of some of the HREPs are shown in table 3.5.

Table 3.5. Level of Protection

Project	Feature	Level of Protection
Andalusia	Levee	2 year
Bay Island	Levee	2 year
Spring Lake	Levee	50 year
	Cross Dike	5 year
Princeton	Levee	15 year
Lake Odessa	Levee	varies
	Upper Spillway	17 year
	Lower Spillway	10 year
Banner Marsh	Levee	50 year
Lake Chautauqua	Cross Dike and Perimeter Levee	10 year
	Radial Gate Structure	10 year
Rice Lake	Control Dike	less than 2 year
Clarksville	Levee	20 year
Stump Lake	Levee	3 to 4 year

Levee Slopes. If the perimeter levee is located adjacent to a major river, its profile parallel to that river may be sloped upstream to allow for gradual overtopping during flood events, which could minimize damage potential. Top widths for a perimeter levee are typically a minimum of 10 feet, especially for those levees that are also used for access (At times the top of the levees are used as a roadway for levee inspections or maintenance). Side slopes are typically a minimum of 3:1 horizontal to vertical. Interior side slopes of 5:1 horizontal to vertical or less can be desired to minimize rodent damage and to minimize erosion caused by overtopping (although conditions in MVS allow for interior slopes of 3H:1V) . Vegetative bank stabilization is often planted to help prevent scouring.

Cells. A MSMU may have a single perimeter levee (1-celled) or consist of multiple cells through the construction of interior cross dikes. When determining whether the levee system should be single or multiple celled, consider the existing site topography. If the site is relatively flat, a single cell may be adequate. If the site varies in elevation, multiple cells may be desired to maximize the acreage of ideal water depth. Also, large MSMU may be portioned into multiple cells for management purposes. The top elevation of a cross dike is typically set to provide a minimum freeboard of 2 feet during the highest ponding scenario.

Spillways. To provide controlled overtopping of a levee system, overflow spillways are constructed, typically at the downstream end of the site, at an elevation lower than the perimeter levee. This elevation provides for overtopping during a lesser flood event. During a flood event, the overflow spillway allows rapid filling of the MSMU interior prior to overtopping of the perimeter levee. The spillway provides a defined location for filling the cells that can be adequately armored and protected against erosion. An overtopping analysis should be conducted to determine the elevation difference between the perimeter levee and the overflow spillway.

Levee Material Sources. When considering options for borrow material for the levee system, it may be beneficial to use on-site material that is suitable. The utilization of interior borrow areas offers additional habitat benefit by converting existing cropland to non-forested wetland. Ideally, these areas would be developed as large and shallow, which would not only maximize habitat benefits but may also yield the most suitable impervious borrow material. Essentially, these borrow areas may be considered potholes. Dredged material from within or outside the levees may also be used to construct the berms. Using dredged material may provide additional aquatic habitat for the HREP.

Maintenance. Maintenance of the perimeter levees, cross dikes, and overflow spillways should include project inspections on an annual basis (ideally after the area is drained) in addition to immediately following a high water event. Project inspections should determine if the following conditions exist; (1) settlement, slough, or loss of section, (2) wave wash and scouring, (3) overtopping erosion, (4) inadequate vegetative cover (too much or not enough), (5) unauthorized grazing or traffic, (6) encroachments, (7) unfavorable tree/shrub growth, and (8) seepage distress. Corrective action should be taken upon discovery of any adverse conditions.

3.5.1.2. Lessons Learned. Lessons learned are described in Table 3..

3.5.1.3. References

EM 1110-2-1603, Engineering and Design - Hydraulic Design of Spillways, CECW-ED-H, 16 January 1990 (original) 31 August 1992 (errata #1), http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-1603/toc.htm

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3.5.2. Pump Stations and Wells

3.5.2.2. Design Methodology and Criteria. Water can be introduced or removed from a MSMU or backwater lake through the use of a pump station, portable pumps, wells or a water control structure. Pumps can obtain either surface water (for example, from the river) or groundwater.

Groundwater. When evaluating a pump station versus a well (i.e. surface water versus ground water), keep in mind that reuse of surface water is desired where practicable. The size and volume of the unit will generally dictate whether a groundwater well can be feasibly constructed. Groundwater wells are limited in capacity due to available well yield from the aquifer, construction limitations, commercially available well pump size, and availability of utility power. There is also a potential of encountering poor groundwater quality (high sulfur, etc.) It may be necessary to incorporate provisions into the design to deal with situations where testing of groundwater quality reveals problems.

Surface water. Surface water is often used as a source due to its abundance and ease of access. When surface water is used, it can remove sediment from its source, and add potentially nutrient rich sediment to the MSMU or backwater lake. Additionally, the use of surface water can remove nitrogen and phosphorous from the river system, with the nutrients eventually being uptaken by plant organisms within the MSMU.

Pump Stations. Pump stations can be designed to have the intake sump and pumps with associated equipment all in one structure or they can be separate. The equipment for both pump stations and wells is required to be at or above certain flood elevations and will depend on where the project is located. Pumping stations can either be a dedicated permanent station or be mobile, including floating type pumping plants.

Water Direction. Pump stations can be designed to pump from the river to the MSMU, from the MSMU to the river, or be multi-directional to pump to multiple MSMUs as well as either way. Extra flexibility may be desired by the project sponsor, although water control could be obtained through the use of various closure structures if so designed.

Pump Size. When determining the size of the pumps for a pump station or well, a minimum of three variables need to be determined; the evaporation rate, the seepage rate, and the desired fill rate.

Energy Source. Pumps may be electric or diesel driven depending upon the availability of utility power and user needs. Electric driven pump stations have the advantage of being quieter to operate (little vibration), easier automation, and less routine maintenance. They may also be submerged and require less labor time to operate. Some of the disadvantages are that the electrical equipment must be protected from flooding, available utility power can limit capacity, high demand charge, and usually larger more elaborate structures are required to house electrical equipment.

Diesel driven pump stations have the advantage of being ideally suited where utility power in unavailable, they have a large capacity, can be permanently mounted pumps with submersible gear drives, can be mounted vertically or angle mounted, can be made trailer mounted to reduce the threat of flooding, and the drive arrangements afford flexibility (direct, belt, hydraulic). Disadvantages to diesel driven pumps are they are noisy to operate, require more routine maintenance, capacity and availability of on site fuel supply can be restrictive, and are difficult to automate.

Maintenance. Maintenance of a pump station or well should include project inspections on an annul basis (ideally after the area is drained) in addition to immediately following a high water event. Project inspections should follow the inspection guide provided later in this chapter and include the following items as a minimum where applicable; (1) structural steel, (2) structural concrete, (3) displaced / missing riprap, (4) electrical lighting / standby generator, (5) discharge pipe, (6) sump, (7) hydraulic pump, and (8) stoplogs. Corrective action should be taken upon discovery of any deficiencies found during the inspection.

3.5.2.2. Lessons Learned. Lessons learned are contained in Table 3..

3.5.2.3. References

EM 1110-2-3104, Engineering and Design - Structural and Architectural Design of Pumping Stations, CECW-ED, 30 June 1989, http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-3104/toc.htm

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3.5.2.4. Case Studies. Case studies are listed in tables 3.6 and 3.7.

Table 3.6. Pump Stations

Andalusia Refuge HREP, Pool 16, Upper Mississippi River Miles 462.0 to 463.0, Rock Island County, Illinois, CEMVR
Banner Marsh HREP, LaGrange Pool, Illinois Waterway River Miles 138.0 - 144.0, Fulton and Peoria Counties, Illinois, CEMVR
Batchtown HREP, Pool 25, Upper Mississippi River Miles 242.5 - 246.0, Calhoun County, Illinois, CEMVS
Bay Island HREP, Pool 22, Upper Mississippi River Miles 311.0 - 312.0, Marion County, Missouri, CEMVR
Calhoun Point HREP, Pool 26, at the confluence of Illinois Waterway River and Upper Mississippi River Mile 220.0, Calhoun County, Illinois, CEMVS; Clarksville Refuge HREP, Pool 24, Upper Mississippi River Miles 275.0 – 275.0, Pike County, Missouri, CEMVS
Lake Chautauqua HREP, LaGrange Pool, Illinois Waterway River Miles 124.0 - 129.5, Mason County, Illinois, CEMVR
Lake Odessa HREP, Pools 17-18, Upper Mississippi River Miles 435.0 - 440.0, Louisa County, Iowa, CEMVR
Peoria Lake HREP, Peoria Pool, Illinois Waterway River Miles 162.0 - 181.0, Peoria and Woodford Counties, Illinois, CEMVR
Spring Lake HREP, Pool 13, Upper Mississippi River Miles 532.5 - 536.0, Carroll County, Illinois, CEMVR
Stump Lake HREP, Pool 26, Illinois Waterway River Mile 7.0 to 13.0, Jersey County, Illinois, CEMVS
Swan Lake HREP, Alton Pool, Illinois Waterway River Miles 5.0 – 13.0, Calhoun County, Illinois, CEMVS
Trempealeau National Wildlife Refuge HREP, Pool 6, Upper Mississippi River Miles 718.0 – 724.0, Trempealeau County, Wisconsin, CEMVP

Table 3.7. Wells

Cuivre Island HREP, Pool 26, Upper Mississippi River Mile 233.0 to 239.0, Lincoln and St. Charles Counties, Missouri, CEMVS
Pleasant Creek HREP, Pool 13, Upper Mississippi River Miles 548.7 - 552.8, Jackson County, Iowa, CEMVR
Potters Marsh HREP, Pool 13, Upper Mississippi River Miles 522.5 - 526.0, Carroll and Whiteside Counties, Illinois, CEMVR
Spring Lake HREP, Pool 13, Upper Mississippi River Miles 532.5 - 536.0, Carroll County, Illinois, CEMVR

3.5.3. Stoplog Structures

3.5.3.1. Design Methodology and Criteria. A general design criteria for this project feature is to construct a structure with operational flexibility that provides the site manager with the capability to meet their seasonal and/or annual management goals. Stoplogs can be placed in various types of structures to meet the sizing requirements for raising or lowering water levels. Additionally, the design of the stoplogs themselves can vary widely. The advantages to using stoplog structures are that they are (1) relatively cheap and (2) low maintenance. Some disadvantages to using stoplog structures may include the following. (1) Removal of a stoplog can in some cases be more than a one-person operation. (2) When the head over the stoplogs is high, removal can become nearly impossible. (3) Stoplogs with eyes at top are difficult to remove and are often hard to hook, which can also cause problems with sealing properly.

Material for Stoplog Structure Housing. Stoplog structures may be constructed of various materials such as concrete, CMP, combination concrete & CMP, PVC, or steel.

> **Concrete** stoplog structures may have single or multiple bays. The concrete structure may be cast-in-place or precast. Additionally, the structure may or may not have footings. Dewatered versus in the wet construction methods should be considered, especially if control of construction costs are critical.
>
> **CMP** stoplog structures generally consist of a 5-foot diameter riser pipe.
>
> **PVC** stoplog structures have not been used extensively for HREP projects but have proven to be successful on other Corps projects so they should be considered for future HREP projects. Stoplog structures may also be designed to have a combination of both stoplogs and sluice gates. The ability to resist deflection and warping must be considered. Protection against damage from ultraviolet radiation is important, because the breakdown of the outer surface can expose glass fibers.
>
> Stoplog structures may also be constructed with **sheet pile cells** as abutments (Batchtown, Swan Lake and Calhoun Point) or with internally tied-back Z-shaped sheet pile wing and face walls (Calhoun Point). Concrete footing structures at the top of each abutment support access bridges and stoplog support framing. These footings may be soil-founded (Batchtown) or pile-founded within the retained embankment (Calhoun Point) as local conditions require.

Material for Stoplogs

> **Aluminum** stoplogs generally weigh less but cost more. While the material weight for aluminum stoplogs is less than wood, hollow stoplogs can accumulate internal silt and thus additional lifting weight over time. Aluminum stoplogs have been designed to have rubber stripping along the bottom and sides to provide a tighter seal. Options for aluminum stoplogs include extruded cross-sections (for individual one-foot stoplogs) or fabricated cross sections of skin plates and connecting members (for one-foot or higher stoplogs). Aluminum stoplogs are also subject to being stolen when aluminum recycling costs are high.

Wood stoplogs are buoyant and require ballasting or some type of mechanism to prevent from floating. Wood stoplogs may have a tendency to seal better as wood will swell when saturated. To help with sealing, wood stoplogs have been designed to have grooves so that they "interlock" when installed, however, this is not always the case (for example at Swan Lake they do not).

Bay Widths. A stoplog structure can involve a series of bays. The stoplog bay width depends on local user requirements. In Rock Island District, a 5-foot bay is often used. At Batchtown (in St. Louis District), several structures are across channels where duck blind access is required. A clear width in each bay of ten feet between stoplog supports, and head clearance of five feet between the maximum water level and the low surface of the access bridge, is provided. At Swan Lake, where such access is not required, the clear opening in each bay is only four feet. If a number of similar structures are anticipated at a project site, using similar bay widths, and therefore similar stoplogs throughout, can provide interoperability.

Height. Structures can vary in height to meet customer requirements. At Swan Lake, a number of both one-foot-high and six-foot-high stoplogs are being provided for flexibility in operation. At Calhoun Point, one-foot-high stoplogs that can be ganged together in the field are being provided. In general, the structure should be located and designed to allow for appropriate drainage or flooding of the site, and to ensure that there is adequate height to maintain water levels upstream of the structure.

Storage. Stoplogs may be stored either off site or on-site, such as in a pump house. If stored on-site, keep stoplogs at the highest elevation possible. It is important to establish storage capabilities of the site managers during the design process.

Protection. Stoplog structures need to be protected from vandalism, theft, and unauthorized use. This can be accomplished through use of padlocks and locking bars. The safety of stoplog structures can be provided through use of inlet/outlet guards, ladders, guardrails, and other such devices.

Lifting Devices. A stoplog lifting hook is typically furnished for the installation and removal of the stoplogs. Lifting devices should be designed for easy transportation and use, especially during high flows. Stop log hoists may be used to manipulate the structure. Lifting devices can be manual or power-assisted. Electric or hydraulic hoists can be used for raising and lowering stoplogs. The lifting equipment can be supported on a trolley beam running across all bays or on a jib crane. The support requirements for a trolley beam or job crane will determine to some extent the layout of the supporting structures at the sides of the channel to be controlled. Jib crane manufacturers can provide anchor bolt patterns and minimum footing requirements to be used in support structure layout. Keep in mind when designing a stoplog structure that some site managers may prefer a one-person operation when installing and removing stoplogs. This can become difficult when the head is too high over the stoplogs, the stoplogs are too heavy, and/or the lifting devices are too bulky.

Top of Structures. If vehicular access across a structure is required, the weight and width of the equipment must be considered. If pedestrian access is required, appropriate safety measures for guardrails, steps, etc. must be included. Additionally, Operator safety should be considered in developing structure features. Non-skid grating and guardrails should be provided on catwalks, etc.

Operation. Stoplog structures should be operated so that when the MSMU is in use or the river water levels are expected to rise, the stoplogs should be installed and are to remain in place until one of the following occurs; (1) flood waters recede, (2) project no longer in use, or (3) overtopping of the perimeter levee is anticipated.

Maintenance. Maintenance of stoplog structures should include project inspections on an annul basis (ideally after the area is drained) in addition to immediately following a high water event. Project inspections should consist of the following to ensure; (1) stoplogs, slots, keepers, staff gages, and lifting hooks are in good condition, (2) steel rails, posts, grating, and fasteners are in good condition, (3) concrete is in good condition, (4) inlet and outlet channels are open, (5) trash, debris, and sediment is not accumulating in and around the structure, (6) erosion, seepage, and encroachments are not occurring adjacent to the structure which might endanger its function, and (7) riprap is not displaced or missing. Corrective action should be taken upon discovery of any adverse conditions at the structures.

3.5.3.2. Lessons Learned. Lessons learned are contained in Table 3..

3.5.3.3. References

*EM 1110-2-2705, Engineering and Design - Structural Design of Closure Structures for Local Flood Protection Projects, C*ECW-ED, 31 March 1994, http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-2705/toc.htm

Agri Drain Corporation, Inline Water Level Control Structures, http://www.agridrain.com/watercontrolproductsinline.asp

EM 385-1-1, Safety – Safety and Health Requirements, CESO-ZA, 03 November 2003, http://www.usace.army.mil/inet/usace-docs/eng-manuals/em385-1-1/toc.htm

EM 1110-2-2100, Stability Analysis of Concrete Structures, CECW-CE, 01 December 2005, http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-2100/toc.htm

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EM 1110-2-2105, Engineering and Design – Design of Hydraulic Steel Structures, CECW-ED, 31 March 1993 (Original), 31 May 1994 (Change 1), http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-2105/toc.htm

EM 1110-2-2503, Engineering and Design – Design of Sheet Pile Cellular Structures, Cofferdams and Retaining Structures, CECW-EP, 20 September 1989 (Original), 11 June 1990 (Errata sheet), http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-2503/toc.htm

EM 1110-2-2504, Engineering and Design – Design of Sheet Pile Walls, CECW-ED, 31 March 1994, http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-2504/toc.htm

EM 1110-2-2906, Engineering and Design – Design of Pile Foundations, CECW-ED, 15 January 1991, http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-2906/toc.htm

3.5.3.4. Case Studies. Case studies are listed in table 3.8.

Table 3.8. Stoplog Structures

Banner Marsh HREP, LaGrange Pool, Illinois Waterway River Miles 138.0 - 144.0, Fulton and Peoria Counties, Illinois, CEMVR
Bay Island HREP, Pool 22, Upper Mississippi River Miles 311.0 - 312.0, Marion County, Missouri, CEMVR
Guttenberg Waterfowl Ponds HREP, Pool 11, Upper Mississippi River Miles 614.0 - 615.0, Grant County, Wisconsin, CEMVP
Pleasant Creek HREP, Pool 13, Upper Mississippi River Miles 548.7 - 552.8, Jackson County, Iowa, CEMVR
Pool Slough HREP, Pool 9, Upper Mississippi River Miles 673.0 - 673.0, Allamakee County, Iowa CEMVP
Potters Marsh HREP, Pool 13, Upper Mississippi River Miles 522.5 - 526.0, Carroll and Whiteside Counties, Illinois, CEMVR
Princeton Refuge HREP, Pool 14, Upper Mississippi River Miles 504.0 - 506.4, Scott County, Iowa, CEMVR
Swan Lake HREP, Pool 26, Illinois Waterway River Mile 5.0 to 13.0, Calhoun County, Illinois, CEMVS
Stump Lake HREP, Pool 26, Illinois Waterway River Mile 7.0 to 13.0, Jersey County, Illinois, CEMVS
Cuivre Island HREP, Pool 26, Upper Mississippi River Mile 233.0 to 239.0, Lincoln and St. Charles Counties, Missouri, CEMVS
Batchtown HREP, Pool 25, Upper Mississippi River Miles 242.5 - 246.0, Calhoun County, Illinois.
Lake Chautauqua HREP, LaGrange Pool, Illinois Waterway River Miles 124.0 - 129.5, Mason County, Illinois, CEMVR
Lake Odessa HREP, Pools 17-18, Upper Mississippi River Miles 435.0 - 440.0, Louisa County, Iowa, CEMVR
Peoria Lake HREP, Peoria Pool, Illinois Waterway River Miles 162.0 - 181.0, Peoria and Woodford Counties, Illinois, CEMVR
Rice Lake HREP, Minnesota River Miles 15.0 – 17.5, Scott and Hennepin Counties, Minnesota, CEMVP
Spring Lake HREP, Pool 13, Upper Mississippi River Miles 532.5 - 536.0, Carroll County, Illinois, CEMVR
Stump Lake HREP, Alton Pool, Illinois Waterway River Miles 7.2 – 12.7, Jersey County, Illinois, CEMVS

3.5.4. Gatewell Structures

3.5.4.1. Design Methodology and Criteria. The primary purpose of a gatewell structure is to provide gravity drainage from the MSMU. It may be desirable to have at least one gatewell structure installed within each cell. A gatewell structure may also be used to enhance MSMU filling operations. If high water events were to occur during the late summer and fall, the gatewell structure could be opened to help capture water, thereby decreasing the pumping requirements. In addition, the gatewell structure may serve as an additional opening for water to enter the MSMU prior to overtopping events.

The gatewell may be cast-in-place with the piping being precast reinforced concrete pipe (RCP). The inverts may also be reinforced with riprap. Stop log structures could be cast-in-place or precast.

Concrete gatewells may be cast-in-place or precast. In some cases this might be specified as the Contractor's option. Weight and size limitations might limit this choice. Gatewells may also be constructed of corrugated metal pipe. Desired level of durability and dewatering requirements during construction will also influence the choice of structure. It is important to consider they expected life of a CMP structure when designing this type of feature.

The type of gate that may be installed is dependent upon the type of gatewell constructed. Sluice gates requiring a flat back for installation require a concrete gatewell. Other types of gates (for example, gates which can be installed on the end of a pipe) are not as dependent upon the type of gatewell structure. The gatewell must provide an operating platform from which the gate may be manipulated and which supports any equipment required to do so. This platform can be steel or fiberglass grating. Guardrails should be provided where required by the safety manual.

3.5.4.2. Lessons Learned. Please refer to table 3.11 for lessons learned.

3.5.4.3. References

EM 1110-2-3104, Engineering and Design - Structural and Architectural Design of Pumping Stations, Appendix C, CECW-ED, 30 June 1989, http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-3104/toc.htm

3.5.4.4. Case Studies. Case studies are listed in table 3.9.

Table 3.9. Gatewell Structures

Andalusia Refuge HREP, Pool 16, Upper Mississippi River Miles 462.0 to 463.0, Rock Island County, Illinois, CEMVR
Batchtown HREP, Pool 25, Upper Mississippi River Miles 242.5 - 246.0, Calhoun County, Illinois, CEMVS
Calhoun Point HREP, Pool 26, Upper Mississippi River Miles 221.0 – 221.0, Calhoun County, Illinois, CEMVS
Clarksville Refuge HREP, Pool 24, Upper Mississippi River Miles 275.0 – 275.0, Pike County, Missouri, CEMVS
Dresser Island HREP, Pool 26, Upper Mississippi River Miles 206.0 – 209.0, St. Charles County, Missouri, CEMVS
Guttenberg Waterfowl Ponds HREP, Pool 11, Upper Mississippi River Miles 614.0 - 615.0, Grant County, Wisconsin, CEMVP
Princeton Refuge HREP, Pool 14, Upper Mississippi River Miles 504.0 - 506.4, Scott County, Iowa, CEMVR
Stump Lake HREP, Alton Pool, Illinois Waterway River Miles 7.2 – 12.7, Jersey County, Illinois, CEMVS
Cuivre Island HREP Pool 26, Upper Mississippi River Mile 233.0 to 239.0, Lincoln and St. Charles Counties, Missouri., CEMVS
Swan Lake HREP, Alton Pool, Illinois Waterway River Miles 5.0 – 13.0, Calhoun County, Illinois, CEMVS
Batchtown HREP, Pool 25, Upper Mississippi River Miles 242.5 - 246.0, Calhoun County, Illinois, CEMVS
Calhoun Point HREP, Pool 26, Upper Mississippi River Miles 221.0 – 221.0, Calhoun County, Illinois, CEMVS
Clarksville Refuge HREP, Pool 24, Upper Mississippi River Miles 275.0 – 275.0, Pike County, Missouri, CEMVS
Lake Chautauqua HREP, LaGrange Pool, Illinois Waterway River Miles 124.0 - 129.5, Mason County, Illinois, CEMVR
Lake Odessa HREP, Pools 17-18, Upper Mississippi River Miles 435.0 - 440.0, Louisa County, Iowa, CEMVR
Spring Lake HREP, Pool 13, Upper Mississippi River Miles 532.5 - 536.0, Carroll County, Illinois, CEMVR
Stump Lake HREP, Alton Pool, Illinois Waterway River Miles 7.2 – 12.7, Jersey County, Illinois, CEMVS
Swan Lake HREP, Alton Pool, Illinois Waterway River Miles 5.0 – 13.0, Calhoun County, Illinois, CEMVS

3.5.5. Sheet Pile Cells

3.5.5.1. Design Methodology and Criteria. Sheet pile cells are fabricated from flat PS-series steel sheets. The number of sheets required for a particular radius cell is standard for a particular width sheet and can be ascertained from manufacturers' handbooks. A cutoff wall of Z-shaped steel sheet piles is driven between the two cells and capped with a sill beam (cast-in-place or precast and grouted onto the cells). Fabricated piles are used to create the connection between the cells and the cutoff wall.

Because the Government is required to purchase American steel, the sources for sheet piling and cross-section profiles allowed are limited. This requirement must be considered in the design stage of a project so the correct cross-sections can be included in the Plans and Specifications. PS- and Z-profile sheets are rolled in this country by Chaparral Steel (http://www.chapusa.com/), which distributes through L.B. Foster (http://www.lbfoster.com/). Additional information on these products is available at http://www.sheet-piling.com/main. Another American supplier of these products is Nucor-Yamato steel (http://www.nucoryamato.com/).

Where sheet pile cells are used as abutments for water control structures, the cells are assumed to be stable within a plane parallel to the axis of the berm (i.e., if the end of the berm is stable in itself, a cell situated within the end of the berm will be stable). Stability in a plane transverse to the axis of the berm is checked, based on the depth of the sheet piling and the internal pressures and external pressures on the cell. The internal pressures will be influenced by the method with which the cell fill is placed.

The need for dewatering of the site prior to placement of the cells must also be considered, because it affects means of construction as well as cost.

Developing a clearly-defined construction sequence is critical for proper installation of the cells. Placement of the cells relative to each other in the field should consider the "bulge" the cells may experience after fill is placed. The resulting clear distance between cells must be considered with regard to installation of footings on top of the cells and stoplog support appurtenances.

Special connection details (e.g., bent plates above the sill analogous to the cutoff wall fabricated piles below the sill) are necessary to provide watertight closure between the cells and the stoplog supports. Selecting steel details that will accommodate the final disposition of the cells, and allowing extra distance between the driven cells to account for bulge, can assist in successful erection of appurtenant details.

Sheet pile cells have provided an opportunity for recycling steel sheet piling originally used for temporary purposes (e.g., sheet piling that had been used in the Melvin Price Locks and Dam cofferdam has since been utilized in cell abutments at EMP projects).

Concrete footings installed on top of the cells support structural/mechanical features such as access bridges, jib cranes, etc. The sheet piling can be used as part of the formwork for these footings. The footings may be supported on the cell fill alone or on foundation piles driven through the fill, as conditions warrant.

Placement of a concrete slab on top of the cell will prevent loss of cell fill in the event a cell is overtopped. Provision of plugged holes in the slab will allow grouting beneath the slab if excessive fill settlement should occur.

Guardrail should be installed around the tops of cells in accordance with the safety manual. In lieu of installing a toeboard, the sheet piling may be cut off four inches above the top of the cell fill/slab. Fiberglass-reinforced plastic guardrails have been used at some locations (Swan Lake); however, because of ultraviolet deterioration and difficulty in making repairs should these items be damaged during floods, wire rope guardrails are an appropriate alternative (Batchtown, replacement of guardrails at Swan Lake).

3.5.5.2. Lessons Learned. Please refer to table 3.11 for lessons learned.

3.5.5.3. References

EM 385-1-1, Safety – Safety and Health Requirements, CESO-ZA, 03 November 2003, http://www.usace.army.mil/inet/usace-docs/eng-manuals/em385-1-1/toc.htm

EM 1110-2-2100, *Stability Analysis of Concrete Structures,* CECW-CE, 01 December 2005, http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-2100/toc.htm

EM 1110-2-2104, *Engineering and Design – Strength Design for Reinforced Concrete Hydraulic Structures*, CECW-ED, 30 June 1992 (original), 20 August 2003 (Change 1), http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-2104/toc.htm

3.5.5.4. Case Studies. Case studies are listed in table 3.10.

Table 3.10. Sheet Pile Structures

Lake Chautauqua HREP, LaGrange Pool, Illinois Waterway River Miles 124.0 - 129.5, Mason County, Illinois, CEMVR
Swan Lake HREP, Alton Pool, Illinois Waterway River Miles 5.0 – 13.0, Calhoun County, Illinois, CEMVS

3.5.6. Rubber Dams

3.5.6.1. Design Methodology and Criteria. Rubber dams are becoming an increasingly popular alternative to more tradition dam structures, as they are easier to install and are more environmentally friendly. Photograph 3.1 and figure 3.1 show examples of rubber dams. The design, installation, and operation of each of these gates are basically identical even if they come from different manufacturers. Each gate uses an inflatable rubber bladder (made from 3.ply nylon) that can be adjusted to produce a desired pool elevation. The first step in the installation of a rubber dam is to construct a foundation structure for the dam. The bladder is then connected to the foundation using anchor bolts and steel plates to clamp the bladder in place. Finally, the bladder is inflated using a blower system with 0.05kgf/cm^2 to 0.6kgf/cm^2 of air (Bridgestone) to the desired elevation. Once inflated, the dam is idle and an air pressure sensor alerts the compressor to keep the dam at a constant pressure. The bladder can also be filled with water.

Photograph 3.1. Typical Rubber Dam Application (Sumitomo Electric)

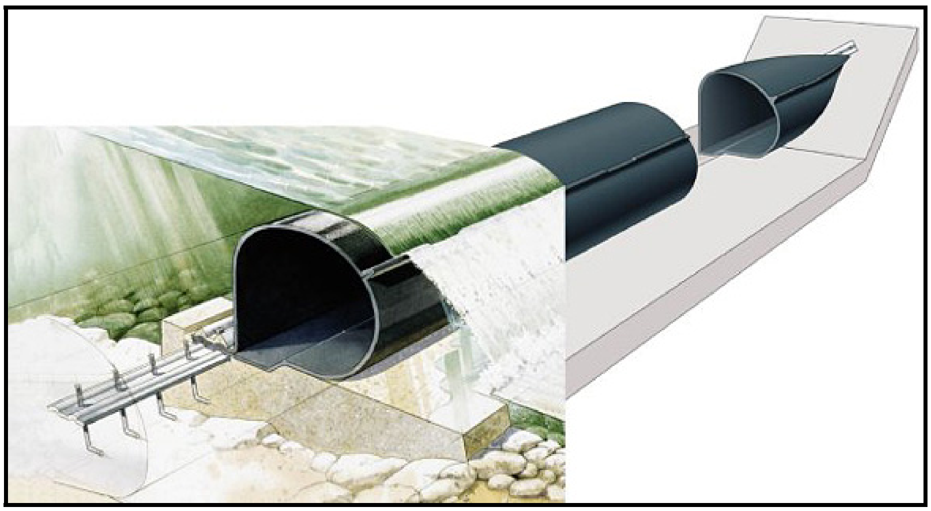


Figure 3.1. Overview of a Rubber Dam (Bridgestone)

Similar to the Obermeyer Gate, the rubber dam can be regulated automatically via an electrical or mechanical control system. A generator is needed to supply the necessary power for the operation of the dam. Maintenance is minimal as there are no moving parts within the dams and they are known to be naturally self-cleaning of debris. Also, according to Bridgestone, debris rarely punctures the bladder. However, like other inflatable dam alternatives, rubber dams are prone to vandalism as they are possible to puncture, resulting in a failure. The cost for a rubber dam depends heavily on the size and other variables; however, the smallest rubber dams generally cost around $200,000 (Bridgestone).

3.5.6.2. Lessons Learned. No lessons learned have been identified to date at HREP sites.

3.5.6.3. References

Bridgestone, Rubber Dam
http://www.bridgestone.co.jp/english/diversified/rubberdam/design.html

Trelleborg, Trelleborg Flexidam, www.trelleborgqr.com/Content/Product_Flexidam1.asp

Sumitomo Electric, Sumigate, http://www.sumigate.com/

3.5.6.4. Case Studies. No case studies at HREP sites had been identified.

3.5.7. Aqua-Barrier

3.5.7.1. Design Methodology and Criteria. The Aqua-Barrier is a water-filled dam that can be used in a variety of applications. Photographs 3.2 and 3.3 show Aqua-Barriers in use. The most common applications of the Aqua-Barrier are flood protection, construction site dewatering, and containing spilled hazardous materials. The barrier is available in a variety of standard sizes, with a height ranging from 2 to 8 ft and a length from 25 to 100 ft (custom sizes are available as well), and is made from a 30 oz. PVC vinyl. The installation and operation of the aqua barrier is relatively simple. The barrier is unrolled and placed along its desired location. It is then filled with water that is pumped from a local source. Once the barrier has been filled with water, it is held in place by its own weight and surface friction (no ties). It is important that the barrier is completely filled with water in order to create a stable structure. The aqua barrier can generally be moved or re-filled 15 to 20 times before it needs replacing.

Photograph 3.2. Installation of an Aqua-Barrier

Photograph 3.3. Inflation and Operation of an Aqua-Barrier (Aqua-Barriers)

Maintenance is minimal as the structure contains no moving parts. In the event of a rupture, the barrier can be repaired without necessarily being completely removed from the field. The cost per linear foot ranges from $19 to $95 (EconoDam), but depends heavily on the site specifications.

The Aqua-Barrier is rather vulnerable to vandalism as it would be fairly easy to puncture the barrier, resulting in a failure. Moving the structure while it is filled with water can also result in a puncture as the structure is extremely heavy and would break easily when in contact with a sharp object. One major concern is the amount of UV that the barrier receives, as too much exposure to sunlight will eventually breakdown the structure and reduce its lifespan to around 5 years. Another disadvantage is that the barrier seems to be more of a temporary structure and may not be suited for a more permanent application even though there have been a few cases of permanent application. Finally, the aqua barrier requires a 20 percent freeboard in order to maintain its stability without floating or rolling. As a result, it would not be possible to run water over the top of the structure and the aqua barrier would not be a suitable replacement for a stop log structure.

3.5.7.2. Lessons Learned. No lessons learned have been identified to date at HREP sites.

3.5.7.3. References

Aqua-Barriers, Water Inflated Dams, http:www.aquabarrier.com
EconoDam, Water Inflated Dam Pricing, http://www.econodam.com/prices.htm

3.5.7.4. Case Studies. No case studies at HREP sites had been identified.

3.5.8. Obermeyer Gates

3.5.8.1. Design Methodology and Criteria. An Obermeyer Gate (photograph 3.4 and figure 3.2) is a spillway/overflow gate that is often used in dam applications. The Obermeyer Gate is composed of steel plates that are supported by an inflatable air bladder on their downstream side. The bladder is made of "A Butyl rubber inner liner provides excellent air retention characteristics. A section of high tensile strength rubber compounds containing multiple layers of polyester or arimid, e.g. duPont Kevlar® tire, cord reinforcement provide the mechanical strength needed to contain the internal pressure. A cover compound utilizing aging and ozone resistant polymers such as EPDM is used to protect the bladder from wear and weathering." (Obermeyer Hydro Inc.). The installation process for the gate is relatively simple. First, anchor bolts are connected to the foundation for the gate. The bladders are then secured to the anchor bolts and are connected to an air source. Finally, the steel panels are attached to the hinge flaps on the bladder.

Once installed, the gate can be raised or lowered by controlling the amount of air that is being supplied to the bladder. Air is not constantly supplied to the bladder. The internal pressure is regulated by a system of valves and is adjusted by an external compressor. A control system can also be used to automatically regulate the elevation of the gate. The two major types of control systems are solar powered and pneumatic water level controls. The solar powered controls use 12 volt solar panels, a battery, and a compressor in order to supply power to the control system and compressor. The pneumatic water level controls are the most popular because they do not require any electrical power. However, most applications involve the use of a generator unless they are small enough to employ the solar power system.

Photograph 3.4. Typical Gate Section - (Obermeyer Hydro Inc.)

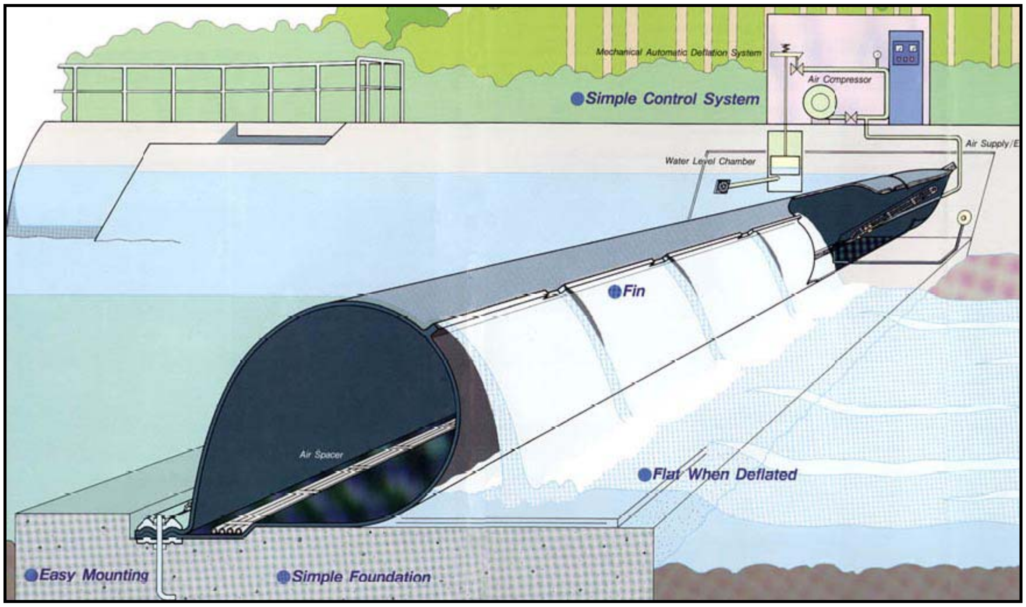


Figure 3.2. Overview of an Obermeyer Gate System (http://www.crrel.usace.army.mil/ierd/tectran/IERD30.pdf)

The profile of the Obermeyer Gate does little to disturb its surrounding environment as debris, ice, and fish can easily pass over the structure depending on its elevation. The major problem associated with an Obermeyer Gate is that it is vulnerable to vandalism. A puncture to the air bladder could cause a section of the gate to deflate completely. Fortunately, the steel panels on the upstream side of the gate form a protective covering over the bladder. Also, depending on the size of the gate, multiple air bladders can be used and separated by check valves so that a puncture to one section of the bladder will not result in a complete failure.

3.5.8.2. Lessons Learned. No lessons learned have been identified to date at HREP sites.

3.5.8.3. References

Obermeyer Hydro Inc., www.obermeyerhydro.com

US Army Corps of Engineers Cold Regions Research and Engineering Laboratory, *Performance Survey of Inflatable Dams in Ice-Affected Waters*, http://www.crrel.usace.army.mil/ierd/tectran/IERD30.pdf

Corporation of the City of London, Environmental Assessment Report Springbank Dam Rehabilitation, http://www.fanshawepioneervillage.ca/Hydrology_&_Regulatory_Service/Springbank_report_without_figures.pdf

3.5.8.4. Case Studies. No case studies at HREP sites had been identified.

3.6 Photographs of Project Features

3.6.1. Perimeter Levees, Cross Dikes, and Overflow Spillways

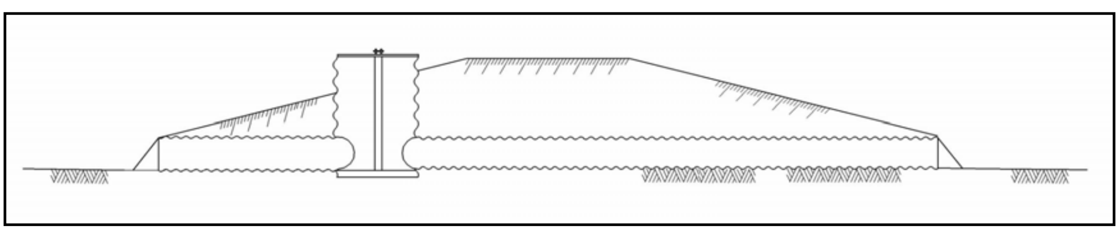
Andalusia Refuge HREP, Pool 16, Upper Mississippi River Miles 462.0 - 463.0, Rock Island County, Illinois, CEMVR

Princeton Refuge HREP, Pool 14, Upper Mississippi River Miles 504.0 - 506.4, Scott County, Iowa, CEMVR

3.6.2. Pump Stations and Wells

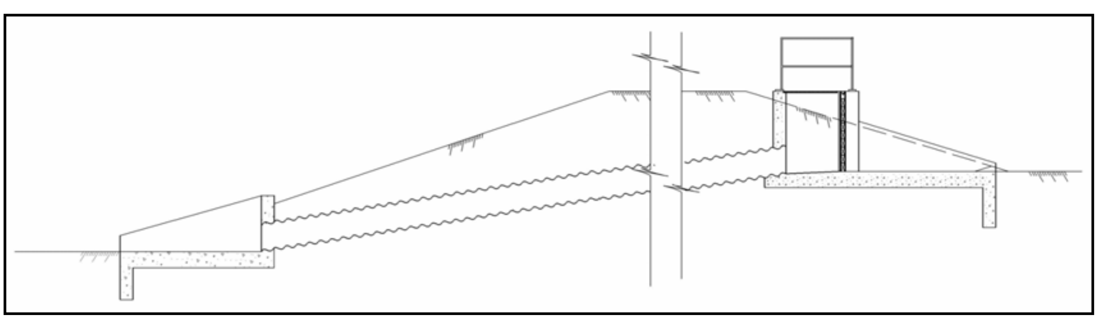
Andalusia Refuge HREP, Pool 16, Upper Mississippi River Miles 462.0 - 463.0, Rock Island County, Illinois, CEMVR

3.6.3. Stoplog Structures



Banner Marsh HREP, LaGrange Pool, Illinois Waterway River Miles 138.0 - 144.0, Fulton and Peoria Counties, Illinois, CEMVR

Bay Island HREP, Pool 22, Upper Mississippi River Miles 311.0 - 312.0, Marion County, Missouri, CEMVR



Potters Marsh HREP, Pool 13, Upper Mississippi River Miles 522.5 - 526.0, Carroll and Whiteside Counties, Illinois, CEMVR

Princeton Refuge HREP, Pool 14, Upper Mississippi River Miles 504.0 - 506.4, Scott County, Iowa, CEMVR

Spring Lake HREP, Pool 13, Upper Mississippi River Miles 532.5 - 536.0, Carroll County, Illinois, CEMVR

3.6.4. Gatewell Structures

Andalusia Refuge HREP, Pool 16, Upper Mississippi River Miles 462.0 - 463.0, Rock Island County, Illinois, CEMVR

Princeton Refuge HREP, Pool 14, Upper Mississippi River Miles 504.0 - 506.4, Scott County, Iowa, CEMVR

3.7 Pump Station Inspection Report

Name of Habitat Rehabilitation and Enhancement Project:

Date/Hour Inspection Began:
Date: Time:

Date/Hour Inspection Ended:
Date: Time:

Inspectors:

Corps Representatives:

Local Sponsor Officials:

River/Forebay Elevations:

River El.: _________ Stage El.: __________ Zero Gage El.: _________
Management Unit El.: _________ Stage El.: __________ Zero Gage El.: _________

Project Data:
Pumping Arrangement and Configuration:

Size of Moist Cell Unit(s) (Acres):

Fill Time (Days):

Empty Time (Days):

General Comments:

3.8. Pump Station Maintenance Inspection Guide

RATED ITEM	A	M	U	EVALUATION	REMARKS
SECTION I				**FOR INTERNAL USE AND EVALUATION**	
1. Pump Station Size				Pump station has adequate capacity (considering pumping capacity, ponding areas, Compare Fill/Empty times with Design, etc.). (A or U.)	
SECTION II				**FOR LOCAL SPONSOR USE**	
2. O&M Manual				O&M Manual is present and adequately covers all pertinent areas. (A or U.)	
3. Operating Log				Pump Station Operating Log is present and being used. (A or U.)	
4. Annual Inspection				Annual inspection is being performed by the local sponsor. (A or U.)	
5. Plant Building				A Plant building is in good structural condition. No apparent major cracks in concrete, no subsidence, roof is not leaking, etc. Intake louvers clean, clear of debris. Exhaust fans operational and Maintained. Safe working environment. M Spalling and cracking are present, or minimal subsidence is evident, or roof leaks, or other conditions are present that need repair but do not threaten the structural integrity or stability of the building. U Any condition that does not meet at least Minimum Acceptable standard.	
6. Pumps				A All pumps are operational. Preventive maintenance and lubrication are being performed. System is periodically subjected to Performance testing. No evidence of unusual sounds, cavitation, or vibration. M All pumps are operational and deficiencies/minor discrepancies are such that pumps could be expected to perform through the next period of usage. U One or more primary pumps are not operational, or noted discrepancies have not been corrected.	

3.8. Pump Station Maintenance Inspection Guide

RATED ITEM	A	M	U	EVALUATION	REMARKS
7. Motors, Engines and Gear Reducers				A All items are operational. Preventive maintenance and lubrication being performed. Systems are periodically subjected to performance testing. Instrumentation, alarms, and auto shutdowns operational. M All systems are operational and deficiencies/minor discrepancies are such that pumps could be expected to perform through the next Expected period of usage. U One or more primary motors are not operational, or noted discrepancies have period of usage.	
8. Sumps/Trash Racks				**SPECIAL INSTRUCTIONS:** Measure silt accumulation in sumps and trash racks. Measure water depth at inlet and outlet. A Sumps/Trash Racks are free of concrete deterioration, protected from Permanent damage by corrosion and free of floating and sunken debris. Sumps are clear of Accumulated silt. Passing debris is minimized by spacing of trash rack bars. Periodic maintenance performed on trash racks and removal of accumulated silt in sumps is performed. M Trash racks and sumps have some accumulated silt or debris but are not currently inhibiting the pump(s) performance. No periodic maintenance has been performed. Present condition could be expected to perform through the next expected period of usage provided removal of floating debris is accomplished. U Proper operation can not be ensured through the next period of usage. Possible damage could result to the pumping equipment with continued operation.	

3.8. Pump Station Maintenance Inspection Guide

RATED ITEM	A	M	U	EVALUATION	REMARKS
9. Other Metallic Items				A All metal parts in plant/building are protected from permanent damage by corrosion. Equipment anchors and grout pads show no rust or deterioration. M Corrosion on metallic parts (except equipment anchors) and deterioration period of usage. U Any condition that does not meet at least Minimum Acceptable standards.	
10. Ancillary Equipment i.e. Compressed Air Siphon Breakers Fuel Supply Vacuum Priming Pump Lubrication Heating/Ventilation Engine Cooling Engine Oil Filtering				A All equipment operational. Preventive and annual maintenance being performed. Equipment operation understood and followed by pump station operators. M Ancillary equipment is operational and deficiencies/minor discrepancies are such that equipment could be expected to perform through the next period of usage. U One or more of the equipment systems is inoperable. The present condition of the inoperable equipment could reduce the efficiency of the pump station or jeopardize the pump station's role in flood protection.	
11. Backup Ancillary Equipment				A Adequate, reliable, and enough capacity to meet demands. Backup units/equipment are properly sized, operational, periodically exercised, and in an overall well maintained condition. M Backup ancillary equipment is operational and deficiencies/minor discrepancies are such that equipment could be expected to perform through the next period of usage. U Backup ancillary equipment not considered reliable to sustain operations during flooding conditions.	

3.8. Pump Station Maintenance Inspection Guide

RATED ITEM	A	M	U	EVALUATION	REMARKS
12. Pump Control System				A Operational and maintained free of damage, corrosion, or other debris. M Operational with minor discrepancies. U Not operational, or uncorrected discrepancies noted from previous inspections.	
13. Intake and Discharge Outlets				Functional. No damaging erosion evident. Opening/closing devices for vertical gates, flap gates, etc. are functional in a well-maintained condition. (A or U).	
14. Insulation Megger Testing (For pump stations with Electric pumps only)				A Megger test has been performed within the last 36 months. Results of megger test show that insulation of primary conductors and electric motor meet manufacturer's or industry standard. M Results of megger test show that insulation resistance is lower than manufacturer's or industry standard, but can be expected to perform satisfactorily until next testing or can be corrected. U Insulation resistance is low enough to cause the equipment to not be able to meet its design standard of operation.	
15. Final Remarks					

3.8. Pump Station Maintenance Inspection Guide

GENERAL INSTRUCTIONS

1. All items on this guide must be addressed and a rating given.
2. The lowest single rating given will determine the overall rating for the pump station.
3. Additional areas for inspection will be incorporated by the inspector into this guide if the layout or physical characteristics of the pump station warrant this. Appropriate entries will be made in the REMARKS block.
4. Rating Codes:
   - A – Acceptable
   - M - Minimally Acceptable
   - U - Unacceptable

SPECIFIC INSTRUCTIONS

SECTION I. Actual fill and emptying times for the project shall be compared with design data and size of management unit to assess adequacy of design.

3.9. Lessons Learned. Lessons learned from various HREP projects are provided in table 3.11.

Table 3.11. Lessons Learned

Topic	Location	Lesson Learned
Botulism	Lake Chautauqua (MVR)	Chautauqua experienced botulism deaths of many migratory waterfowl (waterfowl mortalities in 1997 through 2000 were 8,000, 2,500, 250 and 900). Sick birds generally appear in late August when there are low water levels (2 to 10 inches), low precipitation, and high temperatures for extended periods. These conditions set the stage for the botulism organisms to start reproducing. Birds pick up the toxin and die. Flies lay eggs on the carcasses and the maggots concentrate the toxin to the point where only 3 maggots will kill a duck. The botulism problem usually subsides after the first killing frost. Drying the lake bottom would force the birds to go elsewhere and therefore, avoid the botulism toxins. Therefore, the lower lake dewatering channels was extended from the pump station to the stoplog structure. This required dredging a shallow channel 35 ft wide and approximately 11,000 ft long. The extended channel allows the area to be dewatered completely. This removes the habitat for waterfowl and shorebird use and allows the Site Manager to do complete searches of any remaining small wet areas. If dewatered early enough, the area will produce moist soil plant foods that can be used by waterfowl and other wildlife when re-flooded in the fall. It will also allow the bottom to dry to the point where equipment can be brought into the area to control invasive vegetation such as willow.
Cell Operation	Andalusia Refuge (MVR)	For HREPs with water control structures requiring operation during inclement weather, granular surfacing should be provided along the perimeter levee to strengthen the surface under adverse conditions.
Cell Operation	Bay Island (MVR)	The MSMU was not designed to allow independent operation of the cells. The existing water supply berm was raised and a new gatewell structure was installed in the water supply berm. This added height to the water supply berm in combination with the new gatewell structure now allows independent operation of the cells.
Cell Operation	Princeton Refuge (MVR)	The concrete stoplog structure did not allow for complete drainage of the north cell into the south cell. As a result, two CMP stoplog structures were installed along the cross dike to provide water level control between the cells at lower elevations by gravity flow.
Erosion Protection: Levees	Bay Island (MVR)	Severe erosion along the northwestern edge of the perimeter levee was evident after the Flood of 1993. Approximately 1,070 feet of the perimeter levee toe eroded due to Clear Creek. Clear Creek is a meandering stream that runs along this portion of the levee. The erosion created a 2 to 3.foot vertical cut into the levee toe. The levee slope was re-graded and riprap was placed from the base of the levee toe to 6 feet from the edge of the levee crown.
Erosion Protection: Levees	Peoria Lake (MVR)	The erosion control mats and seeding for erosion control along the levees of Cells B and C were not successful with water level fluctuations, resulting in bank erosion. Traditional riprap was installed in place of these mats at various locations.

Table 3.11. Lessons Learned

Topic	**Location**	**Lesson Learned**
Erosion Protection: Pump Station	Andalusia Refuge (MVR)	Riprap was found to be missing in several areas at the water control structure. However, it was determined that the lack of riprap was not causing any problems.
Erosion Protection: Pump Station	Peoria Lake (MVR)	Erosion occurred around the concrete pad at the pump station outlet. The site manager installed riprap around the concrete pad to help reduce the erosive effects around the pump station outlet.
Erosion Protection: Wells	Potters Marsh (MVR)	The well outlet was provided with a splash pad; however, following testing of the well, it was evident that additional erosion protection would be necessary. To remedy the erosion, a mixture of slush concrete and riprap was placed around the splash pad.
Gatewell	Spring Lake (MVR)	The gate position was difficult to read. The site manager painted the top of the gate stem bright orange to make its position easier to read. Stoplogs are used in the gated inlet structure during maintenance of the structure. The stoplogs are difficult to remove with a high head against them. To ease removal of the stoplogs, the gate is closed temporarily so that water levels are allowed to equalize on either side of the stoplogs.
Guardrails	Swan Lake (MVP)	Fiberglass-reinforced plastic guardrails have been used at some locations (Swan Lake); however, because of ultraviolet deterioration and difficulty in making repairs should these items be damaged during floods, wire rope guardrails are an appropriate alternative (Batchtown, replacement of guardrails at Swan Lake).
Levee Construction	Swan Lake (MVS)	The exterior berm was constructed 1995 and 1996 with large (8 cy) clamshell bucket using lake bottom silts and clays. Portions of the berm have settled more than expected, especially in areas were the berm alignment was across lower elevational areas, such as sloughs. A 5 to 10% design overbuild of berms were to account for anticipated settlement. Some of these areas have now settled below the overflow spillway grade, now making them the low point in the system. The project has experienced overtopping at these low areas and has resulted in higher maintenance caused by washing road stone off of the top of the berm. The low spots of the berms are expected to be brought back up to grade in 2006, subject to funding availability.
Levees: Rodent and ATV Control	Andalusia Refuge (MVR)	Settlement of the levee was discovered due to animal burrowing, unauthorized vehicle use, and scouring and erosion. Trapping has resolved the settlement due to burrowing animals. Unauthorized vehicle use from ATVs and snowmobiles no longer seems to be a problem. The settlement from scouring and erosion also appeared to be corrected.
Levees: Rodents	Spring Lake (MVR)	Since construction has been completed, muskrat burrowing has caused severe erosion on the side slopes and large sinkholes on the levee crown. As a result, water is flowing between the units. This has caused the refuge manger to be unable to manipulate water levels within individual cells as desired. The problem has also become a safety hazard to vehicles traveling on the levee crowns. Annual inspection and maintenance will continue to assess the muskrat damage. One possible solution would be to lay chain link fence fabric on the levee slope, providing a physical barrier to the muskrats. Another possible solution would be to establish an aggressive eradication program, such as trapping. Some site managers claim that having flatter side slopes, such as 10:1 vertical to horizontal, can help prevent muskrat burrowing.

Table 3.11. Lessons Learned

Topic	Location	Lesson Learned
Level of Protection	Bay Island (MVR)	The perimeter levee provides a 2-year level of protection. This level of protection should only be used at sites where impacts of frequent flooding are acceptable for project operation and maintenance. It was recommended that perimeter levees provide at least a 5-year level of protection. A higher level of protection will decrease the rate of sedimentation within the MSMU, increase controlled management opportunities, and decrease the risk of prolonged flooding when trying to establish desired vegetation.
Level of Protection	Spring Lake (MVR)	A 2-year level of protection, as provided by the interior levees (or cross dikes) in Upper Spring Lake, should only be used at HREPs where impacts of frequent flooding are acceptable for project operation and maintenance. Flooding in the spring of 1997 caused damage to some of the embankment materials. The 50-year perimeter levee was not overtopped during the floods of 1997, 1999, or 2001, and is considered an appropriate level of protection.
Pump Cavitation	Banner Marsh (MVR)	The existing pump station structure was modified as part of the HREP to install a new 48" submersible pump. The existing sump was modified and an anti-vortexing plate was installed prior to pump installation. The pump was factory tested but not to the low sump elevation level as specified. After installation, the pump developed a cavitation noise in the sump level operating range during operation of the pump, which has led to complete failure. As a result, heavy rains have caused localized flooding within the MSMU. It may also cause accelerated wear of pump components, thus shortening the expected service life of the pump. The pump was pulled for inspection and measurements with no conclusive findings. The pump was reinstalled with the cavitation noise present and a spare impeller was purchased for replacement in the future. The recommendation has been to continue using the pump as normal. Under normal operation, the 48" submersible pump is a backup that only turns on when the 24" service pump is unable to keep up. The 24" service pump can handle about 90% of the annual MSMU pumping requirements.
Pump Controller Valve	Banner Marsh (MVR)	The 48" pump controller failed twice. The first failure was due to condensation in the pump controller cabinet, which caused a component in the soft start drive to fail. The condensation was caused when the power was turned off to the entire pump station by opening the main breaker. This made it impossible for the pump controller cabinet heater to function and condensation resulted. The Site Manager was instructed to not turn off the main breaker anymore. No O&M Manual was available at the time to provide instruction for pump operation. The second failure was a different component in the soft start drive, which is believed to have failed due to stress caused from the first failure. Both problems were corrected by replacing the faulty components. If further components of the soft start drive fail, it has been recommended replacing the entire drive, which is only one part of the pump controller.
Pump Inspections	Spring Lake (MVR)	The project did not include a system for pump removal so the site manager had to add a jib hoist and crane to the pump station to facilitate removal of the pumps for inspections.
Pump Operation	Banner Marsh (MVR)	A light was installed on the outside of the pump building so that the Site Manager can verify that the pump is running from his house rather than having to drive out to the pump station.

Table 3.11. Lessons Learned

Topic	Location	Lesson Learned
Pump Size	Lake Chautauqua (MVR)	Configuration: Lake Chautauqua pump station is a single submersible turbine that pumps from a lower level pump station to the upper level. It is located at the junction of 2 lakes and the river. It is gate controlled and capable of pumping into or out of any of the 3 water bodies or is capable of gravity flow into or out of any of the 3 water bodies. This configuration greatly increases its versatility and also simplifies pump controls. Pump Size: When the pump station was designed, the pump criterion was to dewater the lower lake in 30 days (allows sufficient time for moist soil production). This resulted in a 41,000 GPM pump. Multiple smaller pumps were ruled out as being too expensive. The design criteria were flawed in the following respect: The pump station has never been used to dewater the entire lake within the 30 day timeframe. The cost to run the pump and pay the demand charges is too costly. The FWS refuge staff would rather wait for the river to drop before dewatering mostly by gravity. In fact, waiting is usually faster. (The pump can pump down a full lake by about 0.10 ft per day). The pump is more than adequate to pump remnants out of the lake and to maintain the lake in a dewatered condition. For these purposes a smaller pump would also work. It would have resulted in less demand and electric charges as well as less submergence requirement and a less expensive pump station.
Pump Station	Andalusia Refuge (MVR)	When the pump was turned on in the fall of 1994 to fill the MSMU, the trash rack clogged with vegetation and cut off the water supply. Subsequently, a chain link fence was installed 6 feet from the pump intake, and an outer mesh fence was installed 100 feet from the pump intake. The outer mesh fence was subjected to damage from ice during the winter of 1995 to 1996. The site manager stated that the fences were not working as intended and had been destroyed by ice, and that the vegetation had filled back in from shore to shore. The trash rack fence system had been designed for those years when there was an excess of floating (or dead) vegetation, river levels were low, and fall pumping was required, which didn't meet the needs of the site manager. It was decided that the outer mesh fence could be removed, leaving the posts in place, and re-installed when needed. Otherwise, if the outer mesh fence remains in place, annual maintenance would be necessary prior to ice-over of the refuge.
Pump Station	Swan Lake (lower compartment), Calhoun Point and Stump Lake (MVS)	At, there are permanent pump stations in which the pump is installed in a slanted intake tube supported in the water on the supply side by a system of piles and cross-beams. The discharge pipe passes through the berm (an embankment created between parallel rows of cross-tied sheet piles) and discharges through a duckbill. The pile support system for the pump allows installation without creating a dewatered location for building a sump. The pump support system must accommodate removal of the pump for maintenance.
Pump Station in Cold Weather.	Banner Marsh (MVR)	The pump floatation system would freeze up so the Site Manager purchased a bubbler system to prevent the floats from freezing.

Table 3.11. Lessons Learned

Topic	Location	Lesson Learned
Pump Station Inlet	Princeton Refuge (MVR)	The river grating on the pump station inlet box has been a challenge. It will plug with debris and create a vortex during pumping operations. It is recommended that a secondary fence be installed between the ends of the wingwalls. This fence would then extend along the top of the wingwalls up to the top of the inlet box to keep debris out during flood events. The grating on top of the pump station inlet box is heavy to remove and replace. Removal and replacement of the heavy grating for maintenance is dangerous to the operator and hazardous to the public if left off. The grating on top of the pump station inlet box was designed to be heavy for safety reasons and to prevent vandalism. If the grating is replaced with a lighter, hinged section, a padlock should be installed.
Pump Station Location	Princeton Refuge (MVR)	During construction, the existing pump station was relocated from the downstream end to the middle of the perimeter levee. However, the existing pump station only consisted of a single pump. As a result, a portable pump with a diesel engine mounted on a highway trailer was supplied following construction.
Pump Station Materials	Spring Lake (MVR)	The door to the pump station rusted on the inside due to moisture. All metal should be galvanized to help prevent rust damage.
Pump Station Siltation	Bay Island (MVR)	The pump station had a continuous problem with the pumping chamber and intake structure filling in with 2 to 3 feet of silt. The silt enveloped the pump impellers, thus making the pump station inoperable until the pumping chamber was cleaned out. In addition, removal of the silt in the pumping chamber had been labor intensive and difficult to complete without easy access to the pumping chamber and intake structure. Silt accumulation in the pumping chamber and around the pump impellers created different power demands on the pump motor. Fluctuation in the pump motor loads or possibly incoming power supply had been throwing the phase converter out of balance. The services of an electrical contractor to recalibrate the phase converter had been needed about twice annually since the pump station had been in service. A sluice gate was installed on the outside of the pump station intake structure and that a platform structure was constructed in the pumping chamber. The sluice gate was placed at the intake of the pump station near the existing trash rack. This gate is closed during non-pumping times to prevent the buildup of silt in the pumping chamber. A platform structure with a ladder was installed to facilitate cleaning out of any silt that collects inside the pumping chamber.
Pump Station Stoplogs	Andalusia Refuge (MVR)	The pump station stop logs would not seal due to the presence of construction debris in the channels. Therefore, the stop log channels had to be cleaned out. Additionally, the stop logs were difficult to remove because of their close proximity to the trash rack. As a result, the pump station trash rack was relocated and a hoist installed.

Table 3.11. Lessons Learned

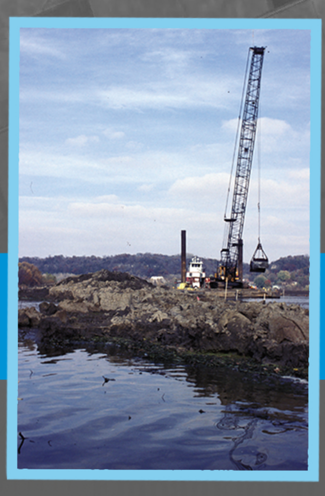
Topic	Location	Lesson Learned
Pumps and Fishing Lines	Princeton Refuge (MVR)	Fishing line has been a challenge with the seals around the pump impeller head. A trash rack cleaning apparatus could be utilized to help with the fishing line. This apparatus would have to be used on a regular basis and could be stored in the pump station engine building.
Sheetpile Cells	Lake Chautauqua (MVR)	The project constructed 4 each 74 ft diameter sheet pile cells. The sheet pile was driven to bedrock and filled with stone. The 4 large cells were connected with arc cells to a lower elevation that would allow complete dewatering of the lake. The arc cells were filled with stone and capped with an H pile supported concrete cap that supported a flood wall and a 10 ft by 10ft heavy duty sluice gate. The main cells included bridges to span the arc cells and provide access to open and close the gates. The bridge abutments were supported on H-piles driven within the main cells. The gates had back-up bulkheads and aluminum stop logs. The upper lake at Lake Chautauqua had a 60 year old water control structure consisting or 4 radial gates 12 ft wide. The gate had not been used for over 30 years. During a flood event, the structure washed out, leaving a large scour hole in the levee system. A flood damage report analyzed various closure alternatives to allow rapid inflow before an over-top event could damage the levee. Other desirable design features were maintaining a consistent water level and increasing the ability to dewater the lake. Analysis showed that another gated concrete structure would be very expensive. Other alternatives included spillways, fuse plug spillway, culverts with gate control, and the selected alternative described below. This design worked well to close the breach in the levee, meet all functional purposes, minimize maintenance, and ease operation. Downstream scour is not a concern and the cost of a stilling basin was eliminated. Used sheet pile was utilized from St Louis District saving additional money. Hydraulics developed an operating plan for when to open the gates. To date the gate plan has worked well and has been used twice. During construction, Engineering used State Plane Coordinates to locate the next main cell after the first cell was constructed and surveyed. Cell spacing was critical so that the gates and floodwall would fit properly. During the gate construction contract, the contractor was required to work up to a designated flood level. He was able to do this by leaving the arc cells extended to the flood elevation and providing interior supports. This worked well and allowed construction within the arc cells during relatively high river levels.
Spillway	Princeton Refuge (MVR)	During the Flood of 2001, the granular surfacing along the overflow spillway was washed to the downstream slope and the geotextile fabric beneath the granular surfacing had been shifted to the downstream shoulder. Despite the disturbance to the granular surfacing and geotextile fabric, the overflow spillway slopes were still intact with most of the vegetation remaining. It appeared that the geotextile fabric had acted as a slippage plane during the flood event for the granular surfacing to “peel” off the overflow spillway. Therefore, the geotextile fabric was not replaced when the overflow spillway was lowered 8 inches.

Table 3.11. Lessons Learned

Topic	Location	Lesson Learned
Spillway	Princeton Refuge(MVR)	The design for the overflow spillway was to be 2 feet lower than the north perimeter levee to allow for rapid filling of the MSMU interior water surfaces prior to overtopping of the perimeter levee. The as-built construction drawings show the final grade of the north perimeter levee at elevation 582.3 feet MSL and the overflow spillway at elevation 580.3 feet MSL, which provides the required 2-foot difference. However, 8 inches (minimum) of granular surfacing was then placed on the overflow spillway. This would place the top of the overflow spillway at approximately elevation 581 feet MSL. A land survey verified that this was indeed the case. The average top elevation of the north perimeter levee was found to be 582.45 feet MSL, while the overflow spillway showed an average top elevation of 581.05 feet MSL. The result was a 1.4-foot difference between the two ends rather than the required 2-foot difference. This discrepancy may have contributed to a large breach in the north perimeter levee during the Flood of 2001. During the flood event, the Site Manager observed that the north perimeter levee and overflow spillway overtopped at the same time, rather than the latter first. As a result, the overflow spillway was lowered 8 inches.
Spillway	Stump Lake (MVS)	The exterior perimeter berm (levee) was designed with a 200 foot long overflow spillway on the downstream portion of the project. The riprap stone was graded stone C (400 lb top size). Severe erosion to the spillway and adjacent berm occurred during an overtopping event in 1997. In 1998, the spillway capacity was reanalyzed and redesigned with larger riprap stone (1,200 lb top size) and 500 feet additional length. To date the spillway has been overtopped numerous times and has maintained its integrity.
Spillway Vs. Stoplogs	Bay Island (MVR)	Overflow spillways were constructed within each cell to allow the MSMU to flood at a set elevation. The overflow spillways help remove the burden of constantly monitoring the river for rising elevations and the need to access the site for removal of all the stoplogs. After the overflow spillways were installed, it was noted that the transition from the perimeter levee crest down to the overflow spillway crest, a 1-foot vertical drop, may be too abrupt at a 10% slope.
Stoplog Materials	Banner Marsh (MVR)	One of the stoplog structures is starting to rust due to the high acidity of the water in the project area or it may be a natural occurrence. The Site Manager may need to repaint this structure.
Stoplog Operation	Banner Marsh (MVR)	The stoplog structures have been difficult to operate. The Site Manager has recommended that the stoplog structures have a sluice gate installed to stop flow. This would facilitate placement and removal of stoplogs. In the other stoplog structure, the stoplogs have a tendency to float. The Site Manager has wedged objects between the C-frame and the end of the stoplogs as a remedial effort to keep the stoplogs from floating. It has been recommended that the stoplog structures have locking mechanisms installed to prevent the stoplogs from floating or the procedure for installing the stoplogs needs to be changed.

Table 3.11. Lessons Learned

Topic	Location	Lesson Learned
Stoplog Operation	Bay Island (MVR)	The water control structures were designed and constructed with the intention of one person removing and replacing the stoplogs. Stoplogs were constructed out of pressure treated Spruce-Pine with a dimensional size of 5'-2½" x 5½" x 2½". However, removal of the wood stoplogs has proven to be more than a one person operation and can often be a struggle for two persons. It was recommended that the wood stoplogs be replaced with aluminum stoplogs, which are lighter. It was also recommended that one of the bays at each structure be converted to a sluice gate, thereby eliminating some of the stoplogs.
Stoplog Operation	Peoria Lake (MVR)	The site manager has expressed the inability to independently operate the three cells, which is undesirable. In addition, there have been challenges in operating the stoplog structures due to the weight of the wood stoplogs. Using solid plates or aluminum stoplogs in lieu of wood stoplogs has been discussed.
Stoplog Operation	Spring Lake (MVR)	Removal of the stoplogs underwater had been difficult. Locating the lifting lugs with the lifting device was a hit-and-miss operation. Therefore, the stoplog lifting device was modified by the site manager to make locating the lifting lugs easier. In addition, the stoplogs do not seal well, allowing seepage between cells. The stoplogs will eventually seal after several days due to fine sediment build-up between the gaps. It has been recommended that the stoplog settings not be changed frequently to avoid breaking this seal. If a more immediate seal is needed, it has been suggested to utilize cinders on the upstream side of the stoplogs.
Vegetation Control (interior)	Andalusia Refuge (MVR)	An abundance of woody vegetation was also reported on several islands in the MSMU. In 1996, the ILDNR Site Manager aerially sprayed the MSMU to control bulrush, lotus, and willow growth. The islands were also burned in 1997 and 1998 to control undesirable vegetation. A beaver dam was found across the main channel. A continual problem in the MSMU is the erosion of the island banks.
Vegetation Control (levees)	Andalusia Refuge (MVR)	In 1997 and 1998, thick woody vegetation was noted as growing among the riprap on the perimeter of the levee. The vegetation was removed and the riprap was sprayed with Round-Up. This process has since been repeated several times.
Vegetation Response on Berms	Andalusia Refuge (MVR)	The perimeter levee was originally seeded with a mixture which was predominantly Indian grass. Initial establishment was successful, however, there was no post-Flood of 1993 re-establishment of the Indian grass on the side slopes of the perimeter levee, nor was the perimeter levee re-seeded. Reed canary grass is now the predominant species. As reed canary grass is very invasive, spraying or controlled burns in the MSMU may be necessary to limit it to the perimeter levee only.



DREDGING

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DREDGING

4.1 Resource Problem

Large river ecosystems support a variety of habitats, of which, backwaters area an integral component. Backwater habitats support many popular sport fishes, waterfowl, shorebirds, and wading birds. Backwaters are also quiet areas off the main channel where people and animals alike can seek refuge.

Because of the widespread loss of backwater and secondary channel depth and depth diversity due to the high rates of sediment, fish habitat quality has decreased, especially in the winter when such areas provide refuge from harsh conditions in main channel areas.

Many Upper Mississippi River System (UMRS) backwaters have been degraded by excessive amounts of sediment emanating from the basin, tributaries, and mainstem sources. This degradation is in the form of loss of depth, poor sediment quality, poor water quality, and sediment resuspension that blocks light required by aquatic plants.

Backwater sedimentation and loss is especially pronounced in lower pools of the Illinois River where sediment from the row crop dominated landscape continues to be excessive. Streambank erosion throughout the basin is another important source of sediment that fills the backwaters.

One solution to this degradation problem is backwater dredging. Backwater dredging typically consists of dredging channels with fingers (dredged channels that extend out away from the main dredge cut). The depth and size (length and width) of the dredge cut depends on several site specific factors.

The sediment dredged to create depth diversity in the backwaters can be used to enhance aquatic areas with islands or terrestrial areas with increase topographic diversity, which promotes the growth of mast trees.

4.2 Dredging for Environmental Restoration

4.2.1 Design Considerations

4.2.1.1 Sedimentation Rates. Sedimentation rates are used to calculate the actual depth of dredging required for the project. Biologists usually provide a depth of water needed to achieve a suitable habitat, either for aquatic vegetation or fish habitat. The depth of dredging is found by taking this provided depth and adding on the expected sediment that will settle in the dredge cut over the life of the project.

Historically, determination of sedimentation rates has been base on sound engineering judgment and the best data available at the time. One such source for sedimentation rates data is the Upper Mississippi River Cumulative Effects Study. In addition, some sampling has been done without recording such information as the climatic conditions when the sample was collected and the coordinates for the sample location. This data helps to look at general trends but cannot be replicated to accurately monitor sedimentation rates over time.

Sedimentation rate estimates will need to be analyzed on a site by site basis using the most recent data available, ideally from the project site or at least from sites with similar features. Table 4.1 is a listing of calculated sedimentation rates for various EMP projects along the Mississippi and Illinois Rivers.

Table 4.1. Sedimentation Rates for Various EMP Projects

Site	River System	River Mile	Years from which Average Rate was Determined	Average Sedimentation Rate (DPR) [1] (in/yr)	Date Project Completed
Andalusia	Mississippi	463.0 – 462.0	1936 – 1987	0.50	Sep1994
Bertom McCartney Lakes	Mississippi	602.8 – 599.0	1938 – 1988	0.39	Oct 1991
Big Timber	Mississippi	445.0 – 443.0	1938 – 1988	0.51	Oct 1994
Brown's Lake	Mississippi	546.0 – 544.0	1930 – 1987	0.45	Sep 1990
Cottonwood Island	Mississippi	331.0 – 328.5	1938 – 1994	0.46	May 2000
Long Island (Gardner)	Mississippi	340.2 – 332.5	N/A	0.21	Sep 2004
Peoria Lake	Illinois	181.0 – 162.0	N/A	1.5	Oct 1996
Pool 11 Islands	Mississippi	592.0 – 583.0	1938 – 1950 1951 – 1995	0.61 0.13	Jul 2005
Potters Marsh	Mississippi	526.0 – 522.5	1938 – 1990	0.25	Dec1995

[1] DPR stands for Definite Project Report and is a planning document for EMP projects

When calculating sedimentation rates for a project, it is important to account for flood events. Flood events drastically increase the sediment delivery of any river and therefore can skew a sedimentation rate that has been calculated for any time frame. Pre-project monitoring, for example, a sediment gage or cross-sectional surveys also aid in the development of an accurate sedimentation rate.

Furthermore, a newly dredged channel in the backwater can act like a sediment trap until it reaches an undeterminable equilibrium. Therefore, in post-project monitoring, the sedimentation rates calculated may be higher than previously estimated. Once the channel and sediment load reaches equilibrium, the sedimentation rate should decrease.

4.2.1.2 Dredge Method. There are two basic categories of dredges, mechanical and hydraulic. Both types of dredges are designed to maximize the quantity of material dredged. While selecting dredge equipment for a project, it should be noted that most dredges are not well suited to efficiently work within small tolerances such as ± 0.1 feet in elevation or in maintaining very specific side slopes.

4.2.1.2.1 Mechanical Dredging. Three types of mechanical dredges include backhoe, clamshell, and dragline. Figure 4.1 shows a schematic of a mechanical dredge and a photograph of a clamshell bucket.

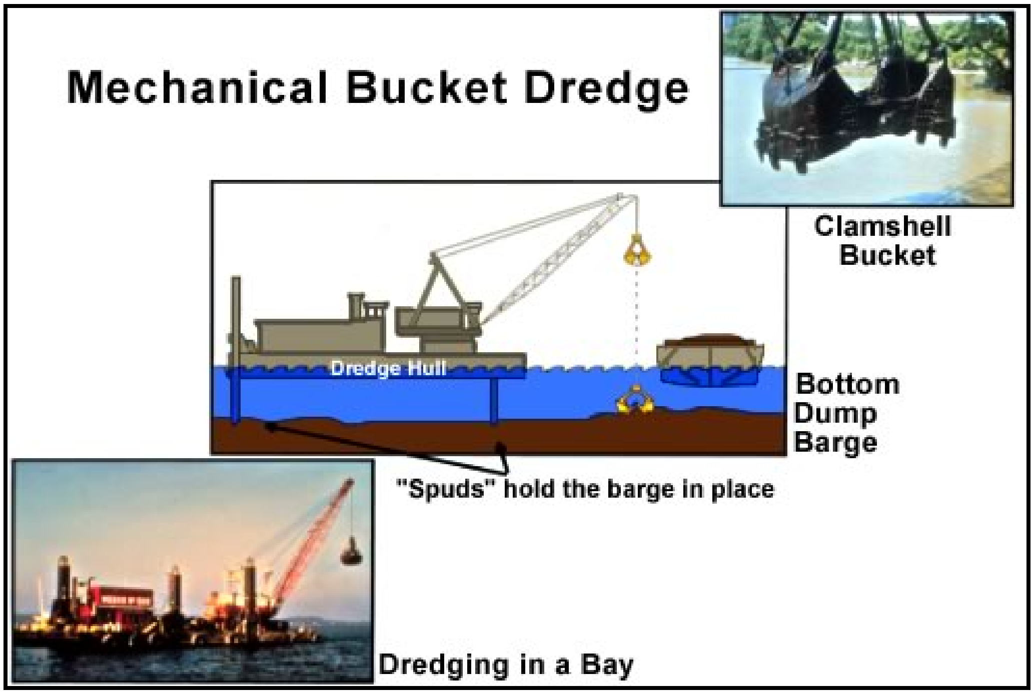

Figure 4.1. Clamshell Dredge

Mechanical dredges are capable of dredging hard packed material and also have the ability to remove debris. For the most part, these types of dredges can work in relatively tight areas and are efficient for side casting material from dredge cut to placement site. Photograph 4.1 shows a clamshell dredge side casting material during the construction of Mud Lake, part of the Pool 11 Islands EMP project. Mechanical dredges are also efficient for transporting material over long haul distances (greater than two miles) and have relatively low mobilization costs. As compared with hydraulic dredging, mechanical dredging does not have the issue of managing return water.

Mechanical dredging generally has lower production rates when compared to hydraulic dredging. It is also difficult to retain fine/loose material in conventional buckets. Mechanical dredging is also inefficient for transporting material over short haul distances (less than two miles). Furthermore, it is not recommended that mechanical dredging by itself be used for contaminated material.

Photograph 4.1. Clamshell Dredge Side Casting Material at Mud Lake, IA

Floating Excavator. A floating excavator as seen in photograph 4.2 is a normal hydraulic excavator with a different undercarriage that gives the excavator a very low ground pressure. This very low ground pressure allows the excavator to work in marsh/wetland type environments where a normal excavator or typical dredge cannot reach.

Photograph 4.2. Floating Excavator

As stated previously, floating excavators are ideal for those hard to reach places and are highly mobile. However, they are not as efficient as the other types of machines discussed earlier in this chapter.

4.2.1.2.2 Hydraulic Dredging. Four types of hydraulic dredges include cutterhead pipeline, hopper, suction, and dustpan. For ecosystem dredging, the hopper, suction and dustpan dredges are not viable options due to their size and difficulty in maneuvering. Therefore, this section will focus on the cutterhead pipeline dredge. Figure 4.2 shows a schematic of a cutterhead pipeline dredge and a photograph of the cutterhead.

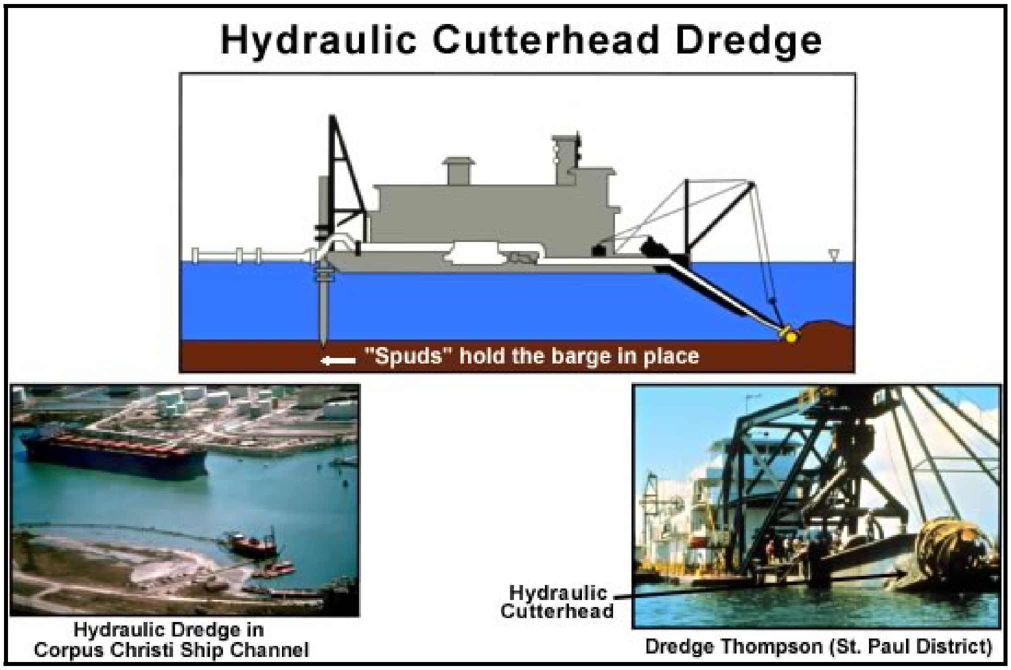

Figure 4.2. Hydraulic Cutterhead Pipeline Dredge

Cutterhead pipeline dredges are sized based on the discharge pipe inside diameter and are typically available from 8-inch to 20-inch with larger applications reaching 36-inches or more. Table 4.2 shows the various EMP projects that have used hydraulic dredging in their construction.

Table 4.2. Hydraulic Dredge Sizes at Various EMP Projects

Project	River System	River Mile	Dredge Quantity (CY)	Size of Cutterhead (in)
Bertom McCartney Lakes	Mississippi	602.8 – 599.0	400,000	16
Long Island (Gardner) Division	Mississippi	340.2 – 332.5	83,000	8
Big Timber	Mississippi	445.0 – 443.0	143,000	8 – 10
Brown's Lake	Mississippi	546.0 – 544.0	370,000	10 – 14

Cutterhead pipeline dredges are capable of excavating most types of material and can even dredge some rock without blasting. Unlike mechanical dredging, hydraulic dredging allows for direct placement of material into a placement site. Hydraulic dredging also allows for the ability to pump almost continuously which results in higher production rates than mechanical dredging. This method is also very cost effective if within economical pumping distances of placement site (less than 2 miles).

Cutterhead pipeline dredges, however, have a difficulty with coarse sand in high currents. In general, these types of dredges are sensitive to strong currents. Therefore, provisions should be made in the plans and specifications of any project to allow for down time for dredging in case of flood events. Another provision to put in the specifications is the passage of other motor vessels as the pipelines and/or wires associated with hydraulic dredging may obstruct navigation. Other disadvantages of this type of hydraulic dredging are that cohesive material and debris can block cutterhead which can in turn reduce efficiency. The dredging slurry is 80 to 90% water (the other 10 to 20% is sediment) which can cause difficulties in obtaining and administering a water quality permit. Since this water has to be returned back to the source, return water management must be incorporated into any design. Lastly, hydraulic dredging also has high mobilization costs when compared to mechanical dredging.

High Solids Dredging. High solids dredging, also known as Dry DREdge™, is a very useful technique. This technique utilizes mechanical dredging to produce a slurry that is 80% solids, thus resulting in a relatively clean effluent. This technique can be used to fill geo-tubes, which can in turn be used to build form the outer ring of an island. High solids dredging is one of the only techniques suitable for building islands out of a highly silty material. This technique is also used when contaminants are present in the sediment.

4.2.1.3 Production Rates. Production rates are the amount of material, usually measured in cubic yards (CY), a dredge can remove per unit of time, usually expressed per hour. Production rates are useful to help determine the construction schedule of a project. Production rate estimates should be one of the basic components in determining the length of a construction contract. When estimating the production rate, research should be done so that the production rate accurately depicts what will occur in the field.

4.2.1.4 Dredge Cut Dimensions. Dredge cuts for environmental restoration are very site specific. There are several factors that should be taken into consideration when designing a channel. Some factors are biological concerns, logistics of dredge equipment mobilization, and hydrology and hydraulics.

Determination of the desired dredging depth includes assessment of typical water level elevations, present low-flow winter regulations, desired maintained water depth and projected sedimentation over the project life. Typically, the maintained water depth is determined from the anticipated maximum ice depth and the desired maintained water depth below that ice. A rule of thumb for the upper Midwest is to allow for a maximum ice depth of two feet and a desired water depth of two to four feet below the ice. This translates to a maintained water depth in the four to six foot range with six feet being a commonly accepted depth. It should be noted however that flow conditions can alter the formation of ice, for example, higher flows does not allow the water to freeze; therefore, a hydraulic analysis should be done to determine what flows will be present and if that flow will allow ice to form.

Caution should be used to avoid dredging to elevations greater than those required to establish the maintained water depth as this could result in the loss of littoral habitat.

Width of the dredge cut will be determined by existing channel conditions, project requirements, placement site capacity, and project funding. Typically, dredge cuts are designed based on a bottom width. Table 4.3 lists various dredge cut dimensions for various EMP projects.

In-depth geotechnical analysis needs to be performed to determine the type of material that is being dredged so that the proper side slopes can be designed. In some cases, the channel has been dredged with vertical side slopes, and the material is allowed to slough to its natural angle of repose. This helps to minimize the project cost by reducing actual dredging time and quantities.

Table 4.3. Dredge Cut Dimensions for Various EMP Projects

Project	River System	River Mile	Width (ft)	Depth (ft)	Slope (H:V)
Andalusia	Mississippi	463.0 – 462.0	30-60	7	2:1
Cottonwood	Mississippi	331.0 – 328.5	50	7	Vertical
Long Island (Gardner) Division	Mississippi	340.2 – 332.5	50	7.5	Vertical
Potter's Marsh	Mississippi	526.0 – 522.5	50	8-10	2:1
Big Timber	Mississippi	445.0 – 443.0	30-50	4-9	2:1
Brown's Lake	Mississippi	546.0 – 544.0	30	9	2:1
Pool 11 Islands	Mississippi	592.0 – 583.0	33	8	3:1

4.2.1.5 Deep Holes. Deep holes are dredged "pockets" of deeper water that provide habitat for fish. Deep holes are typically dredged to a depth of 20 feet below the flat pool elevation and vary greatly in size. Either a mechanical or hydraulic dredge can be used to construct a deep hole, depending on the size. For smaller deep holes, a mechanical dredge should be used as it will be difficult to maneuver the cutterhead on a hydraulic dredge. Special attention should be paid to the sedimentation rates in the area of the deep hole as these cuts have more of a tendency to act like sediment traps.

4.2.2 Monitoring the Dredge Cuts. Monitoring of the dredge cuts should start as soon as they are constructed. Monitoring this early will aid in the determination of the sedimentation rates for the new dredge cut. To maintain consistency, survey monumentation should be coordinated with any individual who could monitor the project. These individuals could include surveyors, hydrologists, fish biologists, etc. The survey monuments should be positioned such that they will be easily used and not deteriorate through the life of the project.

4.2.3 Common Problems Associated with Dredging. Most difficulties in dredging do not shut the operation down for long periods of time. The most common problem associated with hydraulic dredging is damaging the cutterhead. Another problem is access into backwater sites. Most problems, except for equipment failures, can be avoided by obtaining as much information about the bathymetry and hydraulics of the site and providing that in the plans and specifications that the contractor will utilize to construct the project.

4.2.4 Lessons Learned

- Document assumptions made about production rates estimated during the planning and plans and specifications phase of a project. This documentation will help evaluate a contractor's proposal to construct the project. Also, document the contractor's actual production rate to add to record for future reference.
- Always keep in mind the water quality restrictions on return water. This can drastically alter the method of sediment removal.

- Make sure the contractor is aware of the flooding frequency of the area.

- Layout the schedule of the project such that the likelihood of the contractor mobilizing twice is minimal.

- Dredging is very site specific – each reach of any river has its own characteristics that need to be studied and monitored to achieve a lasting design.

- Estimating the sedimentation rate during planning and plans and specifications phases is vital to the success of the project. If the sedimentation rate is significantly inaccurate, the project may have to be dredged midway through the life of the project at the sponsor's expense.

- Inlet channels that are directly perpendicular to the flow path of the main channel typically silt in faster than an inlet channel that is not.

4.2.5 Case Studies

Bertom and McCartney Lakes (UMRS River Mile 602.8 to 599.0). This project incorporated a partial closing structure, fish and mussel rock habitat, and dredging to meet project objectives. Dredging features included deep water habitat, an increase in dissolved oxygen (DO), and a minimum water depth of six feet over the project life with a 10 foot minimum depth adjacent to the railroad tracks. Dredged material was used to build a kidney shaped island with a perched wetland. The island has significant waterfowl populations.

Brown's Lake (UMRS River Mile 546.0 to 544.0). This project included construction of deflection levee, a water control structure, improved inlet side channel, side channel excavation, lake dredging, terrestrial dredged material placement, and planting of mast trees.

The dredging components included the inlet channel improvement to reorient the mouth downstream to minimize debris and bedload sediment from reaching the new water control structure.

In addition, lake dredging was performed to maintain a minimum water depth of five feet below flat pool elevation. Deep holes that were 20 feet in depth were dredged for diversity. The placement site was replanted with mast trees.

Peoria Lake Enhancement (Illinois Waterway River Mile 181.0 to 162.0). This project included construction of a forested wetland management area, a barrier island, and restoration of a flowing side channel.

The barrier island was constructed using mechanically dredged soft sediments with gentle placement on the adjacent site using multiple passes for island stability. A minimum seven cubic yard clamshell bucket was included in the dredging scope. This requirement slightly increase the mobilization costs (the contractor was from Louisiana) but it drastically reduced the per unit cost of dredging the material. A clamshell bucket was selected because it can excavate large soil masses without significantly disturbing the internal strength of the soil and it produces the least turbidity compared to dragline or backhoe buckets. This type of dredging was selected due to its cost effectiveness, maximization of soft sediment placed on the island that promotes re-establishment of vegetation for habitat enhancement.

4.2.6 References

U.S. Army Corps of Engineers, *EM 1110-2-5025, Dredging and Dredged Material Disposal* March 25, 1983.

U.S. Army Corps of Engineers, *EM 1110-2-5026, Dredged Material Beneficial Uses* June 30, 1987.

U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, *EPA-823-B-98-004, Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. – Testing Manual, Inlands Testing Manual*, February 1998.

U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, *EPA842-B-92-008*, *Evaluating Environmental Effects of Dredged Material Management Alternatives – A Technical Framework*, November 1992.

U.S. Army Corps of Engineers, *Dredging Operations Technical Support Program*. http://el.erdc.usace.army.mil/dots/dots.html

U.S. Army Corps of Engineers, *Dredging Operations and Environmental Research*. http://el.erdc.usace.army.mil/dots/doer/doer.html

4.3 Dredged Material Placement and Uses in Environmental Restoration

4.3.1 Design Considerations. Placement sites for dredged material may be located upland out of the floodway, along the bankline, or in water. They may be Confined Disposal Facilities (CDF) incorporating perimeter berms to confine the dredged material and return water, if applicable, or open sites allowing easy access for placement sites and shaping of the dredged material. A list of potential placement sites that meet project goals and objectives should be developed for evaluation.

Over the years, more efficient and worthwhile uses of dredged material, rather than just storing it on the bankline or in a CDF, have been developed. This trend has greatly impacted the use of dredge material in environmental restoration. Dredged material is used to build islands, construct levees or berms, and create floodplain depth diversity.

4.3.1.1 Conventional Placement of Dredged Material. Once a list of potential placement sites has been developed, a search of existing databases, maps and other sources should be completed to identify any known issues or concerns. Some possible issues or concerns are:

- Impacts to wetlands, endangered species, water quality, aquatic, and terrestrial species
- Floodway conveyance, flood heights, and flood storage impacts
- Existing land uses
- Real Estate issues
- Hazardous, Toxic, and Radioactive Waste (HTRW) concerns
- Beneficial uses

4.3.1.2 Restoration Uses for Dredged Material

Island. The main restoration use for dredge material is for island building. This is a very beneficial use because the haul distance from the dredge cut to the island site is usually very minimal. In most instances, the material is sidecast to build the island. Refer to Chapter 9, *Island Design* for more information on island building.

Levee. Dredged material can also be used to build a new levee or strengthen an existing levee as part of a moist soil unit. Attention needs to be paid to the type of material being dredged so that the proper side slopes and compaction requirements are met. This will help ensure stability of the structure. Refer to Chapter 3, *Localized Water Level Management* for more information on levees and moist soil units.

Floodplain Depth Diversity. Dredged material can be placed in a variety of places to increase floodplain depth diversity and habitat. Dredged material can be placed on existing islands, banklines, and uplands. These areas are typically planted with mast trees. Refer to Chapter 7 of this handbook to for more information on floodplain restoration.

4.3.2 Lessons Learned

- The sediment to be dredged should be thoroughly tested for contaminants. If the tests results show an unacceptable level of contaminants in the sediment, an environmental engineer should be consulted. Presence of contaminants in sediment can severely limit what can be done with that sediment.

- Typical permits required for dredging and dredged material placement include NEPA, CWA section 404(b)(1) compliance, state floodplain permit, section 401 water quality certifications and if applicable, a state floodplain construction permit and CDF permit

- When placing dredged material in and around mature trees, the depth of the material should be minimized so as to not kill the trees

4.3.3 Case Studies

Potter's Marsh (UMRS River Mile 526.0 to 522.5). Included construction of a sediment trap, dredging was done in the upper/lower sloughs and embayment areas creating both shallow and deep water habitat, pothole excavation, and construction of a managed marshland.

Dredged material was placed in a confined disposal site located in an area of secondary growth adjacent to Central Island. The location and shape of the placement site were defined so as to not inundate the lower lying marshland areas downstream and to the east as well as the heavy timber and natural potholes to the north.

Column settling analyses were performed to determine the required detention time and total for initial dredged material containment. The dredged material needed about 25 hours of settling time and required an initial volume of approximately 1.75 times larger than the in situ sediments. Based on these analyses the interior area of the placement site needed to be 35.5 acres with a perimeter dike of 14 feet in height.

The dredged material was placed to an initial depth of 12 feet, settling to a depth of 8 to 10 feet after the first year. At that time, the perimeter dike upper surface was lowered to approximately 2 to 3 feet above the dredged material.

After settlement of the dredged material, an approximate 32.5 acre marshland was constructed on the confined placement site.

Long Island (Gardner) Division (UMRS River Mile 340.2 to 332.5). Included side channel restoration and protection within O'Dell Chute including a closure structure along with shoreline protection and reforestation.

The material dredged from O'Dell Chute and the closure structure access channel was placed on a 184 acre agricultural field on the eastern end of Long Island. It was determined that up to 8 inches of the sandy dredged material could be incorporated into the existing soil and still support the reforestation plan. To ensure that this depth was not exceeded, a 60 to 80 acre site was used. A berm was constructed on three sides of the placement site to ensure the dredged material settled out before draining to Long Island Lake. The berm is 2 feet in height with 2H:1V side slopes. It was assumed that the fine to medium sand making up the dredged material would settle quickly, therefore a column settling analysis was not performed.

4.3.4 References

U.S. Army Corps of Engineers, *EM-1110-2-5027, Confined Disposal of Dredged Material*, September 30, 1987.

U.S. Army Corps of Engineers *ERDC/EL TR-03-1, Evaluation of Dredged Material Proposed for Disposal at Island, Nearshore, or Upland Confined Disposal Facilities Testing Manual, Upland Testing Manual,* January 2003,

U.S. Army Corps of Engineers, *ERDC-TN-DOER-C18, Confined Disposal Facility (CDF) Containment Features*, August 2000.

U.S. Army Corps of Engineers*, ERDC TN-DOER-C18, Confined Disposal Facility (CDF) Containment Features: A Summary of Field Experience*, August 2000.

RIVER TRAINING STRUCTURES &
SECONDARY CHANNEL MODIFICATION

CHAPTER 5

UPPER MISSISSIPPI RIVER SYSTEM
ENVIRONMENTAL DESIGN HANDBOOK

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CHAPTER 5

RIVER TRAINING STRUCTURES AND SECONDARY CHANNEL MODIFICATIONS

5.1. Resource Problem

River training structures were originally and continue to be used to create and maintain a safe and dependable navigation channel for the Mississippi Inland Waterway System. In the past, the navigation channel was typically developed by constricting the channel and closing off side channels. As we have become more environmentally conscious we continue to develop intuitive designs using river training structures, incorporating both navigation and river restoration. The Upper Mississippi River as a large ecosystem supports a variety of habitats, of which, backwaters are an important component. Backwater habitats support many popular sport fishes, waterfowl, shorebirds and wading birds. Backwaters are also quiet areas off the main channel where people and animals alike can seek refuge from the busy main channel environment. Along with river training structures, the navigation locks and dams were constructed on the River in the 1930s to maintain the navigation channel. As a result, the river was transformed from a meandering river connected to the floodplain into a series of pools with a mandated minimum depth. In braided channel habitats of the northern river reaches, side channels are numerous and provide a variety of habitat conditions. Further south, side channels are typically larger and more uniform in their configuration. Side channels have been degraded by sedimentation and channelization. The system that was created by the river training structures and the locks and dams was not sustainable. The disconnection has lead to a number of problems some of which are listed below;

5.1.1. Meandering River Channel. As a typical alluvial channel the Mississippi River likes to meander back and fourth along it’s floodplain, constantly realigning itself. This natural meandering process is the rivers attempt to restore balance in the system by eroding its banks, reducing the overall energy in the system. As the Mississippi River travels south, sinuosity increases linearly, as velocities increase. The bends create a hindrance to the navigation industry and also to the Corps who must maintain the navigation channel.

The outside of a river bend is the location of the majority of the channels energy. Depending on the bank material, the river likes to erode the bankline and eventually cut new channels in areas where it makes sharp twists and turns. This incorporates additional sediment to the system which must be deposited downstream.

In places where the current hits a protruding river bank, it begins to wear down the exposed bank, eventually forming a side channel and later a main channel.

5.1.2. Eroding Banklines. Banklines on both sides of the river are exposed to erosion. The bankline along the fast moving side of the river is exposed to the river’s relentless current, scouring above and below the water line. The river bank running along the slow side of the river can also be exposed to erosion. Wind, rain, man, and the river itself all contribute to the loss of bankline stability.

5.1.3. Tributary Effects. Tributaries introduce a large portion of sediment into the system. Land use change, whether it has been urbanization or agricultural fields, has played a major role in the stabilization of tributary banks. Many of the riparian corridors have been destroyed and channel straightening has occurred. Unvegetated banks contribute to excessive erosion and channel straightening leads to headcutting, which induces massive bank failures due to downcutting. All of the added sediment in the tributaries is eventually passed to main stem, in this case the Mississippi River. This has a major impact on the Mississippi Rivers ability to transport sediment and maintain backwater sections of the river.

5.1.4. Sedimentation/Navigation Concerns. Each year the Mississippi carries approximately 130 million tons of sediment to the Gulf of Mexico. That which does not reach the Gulf adds approximately 300 yards to the State of Louisiana each year. The rest is deposited in the river channel. How much and where depends on the velocity of the river and the size and depth and width of the channel.

Historically, dikes and other river training structures were strictly used to constrict flow, increasing the channels ability to transport sediment. This was done to maintain a safe and dependable navigation channel. Today, river training structures continue to maintain the navigation channel but new designs attempt to preserve and enhance the environmental component of the channel.

Streambank erosion throughout the basin is another important source of sediment filling backwaters. Backwater restoration is required throughout the UMRS.

5.1.5. Sedimentation/Biological Concerns. Sedimentation is a naturally occurring phenomenon. Traditionally, it is managed through the use of river training structures and mechanical dredging. Disposing of the dredge material in an appropriate manner can also negatively impact the environment.

To a biologist, sedimentation is the process of turning an aquatic environment into a terrestrial habitat. While both environments are looked on favorably by the biologists, eliminating one in favor of another is unhealthy. Healthy ecosystems need a variety of diverse environments.

Sediment diminishes the river by destroying aquatic life. Biological diversity is best achieved with a variety of river habitats including slow water and wetted edge, often found along banklines. The effects of sediment deposition, and sediment resuspension that blocks light required by aquatic plants resulting in loss of aquatic plant communities, shoreline erosion, and secondary channel formation has resulted in degraded habitat in the navigation pools.

5.1.6. Homogeneous Environments. One long, deep river creates a homogeneous environment that is unhealthy to the ecosystem. Ecosystems are built on food webs. Protozoa are consumed by insects, which are consumed by small fish. They small fish are consumed by large fish that are consumed by man and other predators. Different species require different habitats to breed, raise their young and survive. The healthiest ecosystem offer diverse habitats accommodating the greatest number of species.

5.1.7. Narrowing of Channel Widths In River Bends. Since the late 1800s, when revetment and stabilization work began, the river has found ways to challenge man’s ability to harness it tremendous energy. Because the lateral erosion or meandering movement of the river has been held in check by these stabilization methods, the river has responded by diverting its lateral energy downward. This has caused a significant deepening of the river bends.

Sandbars on the inside of these bends formed points, commonly called point bars, which encroached into the navigation channel. The result has been the development of a severely narrow, deep, and swift navigation channel. The negative impacts of these river bendways create destruction and costs of great magnitude to both the navigation industry and the environment.

5.1.8. Environmental Impacts of River Bends. The U.S. spends millions of dollars each year dredging point bars in troublesome bends to keep the navigation channel open. This remedial measure only serves as a short, temporary cure. The river naturally replaces the sediment during high water events. Frequent dredging also puts unwanted strain on the environment by releasing unnatural levels of suspended sediment and toxins from the sediment.

Information on these impacts can be found at the USACE, St. Louis District web site http://www.mvs.usace.army.mil/engr/river/EnvironEng/en01.htm, "Environmental River Engineering on the Mississippi."

Excessive bankline erosion and overbank scour are phenomenon caused by river conditions that exist in some bends. Although revetments usually protect the banklines, the bends are subjected to a tremendous amount of force from excessive currents. These conditions may lead to serious bankline and overbank erosion resulting in loss of adjacent wetlands and farmland.

In some bends, dikes were constructed on the sandbar side of the bendway in an attempt to improve the navigation channel. The Least Tern, a federally endangered species, uses many of these sandbars as nesting habitat. Dike construction on these sandbars may endanger or even eliminate the bendway's natural habitat.

Training structures can be used to alter hydrodynamic conditions, the sediment transport regime, and ultimately habitat conditions on the UMRS. The impacts of channel training structures are most evident in the southern pools and the Open River. They tend to cut off flow and increase sedimentation in side channel areas. Bank revetments prevent erosion and maintain a stable channel, but they have largely arrested new habitat creation. Wing dams also provide flow refugia and may support large concentrations of fish adapted to moderate flow. The rock revetment provides structure for dense aggregation of macro-invertebrates, (Upper Mississippi River and Illinois Waterway Cumulative Effects Study, US Army Corps of Engineers, Rock Island District, June 2000, page 130).

In the St. Paul District, secondary channel restoration projects typically introduce flow into isolated channels or restrict flow into channels to reduce sedimentation and current velocity. The St. Louis District is pursuing projects to open the upper end of secondary channels, with the goal of introducing flow and improving water quality. Possibly, the most innovative secondary channel projects in development are being designed for Middle Mississippi River reaches that have not benefited from HREPs to date.

Typical river training structures and side channel enhancement structures/techniques that are discussed in this document are shown in table 5.1.

Table 5.1. River Training and Side Channel Enhancement Structures/Techniques

Structure/Technique
Closure Structures
Wing Dam Notching
W-Weirs
Notched Closure Structures
L-Head Dikes
Spur Dikes
Alternating Dikes
Stepped Up Dikes
Bendway Weirs
Blunt Nosed Chevrons
Off Bankline Revetment
Hard Points in Side-Channels
Vanes
Cross Vanes & Double Cross Vanes
J-Hook
Multiple Roundpoint Structures
Environmental Dredging
Longitudinal Peak Stone Toe (LPSTP)
Wood Pile Structures
Root Wad Revetment
Woody Debris
Boulder Clusters
Fish Lunkers

5.2. Closure Structures

Closure structures are constructed across secondary channels, to reduce floodplain conveyance and increase main channel depths.

Rock is used to partially or completely close secondary channels on the Upper Mississippi River. In geomorphic regions 1 through 4, the long term trend is for floodplain conveyance to increase so secondary channel closures are used to reverse this trend.

Most of the land and geomorphic areas found in the river valley are affected by secondary channel closure construction. This includes areas associated with channels, floodplains and natural levees.

Secondary channel closure elevations should be constructed to the bankfull elevation or less. This increases the amount of floodplain conveyance that occurs during flood events, restoring a more natural flow and sediment transport. If the secondary channels closure elevations were lower than the adjacent natural levees, erosive forces on the natural levees are reduced during floods.

5.2.1A. Design Methodology: Emerged Closure Structures

Top Elevation. Emerged secondary channel closures (i.e. those with a top elevation greater than the low water surface elevation) are generally constructed to the bankfull flood elevation or less. This maintains floodplain conveyance and restores a more natural flow and sediment transport regime. If secondary channel closure elevations are lower than the adjacent natural levees, so that flow occurs over the closure structure first, then the water surface differential and erosive forces on the natural levees are reduced during high water events. A low flow notch is often included in closure structures to allow continuous flow of water during low flow conditions and boat access. Photograph 5.1 illustrates a common closure structure design, (Jon Hendrickson, MVP 2005).

Photograph 5.1. Partial Closure Structure at the Weaver Bottoms Secondary Channel, in Pool 5

Width. Although emerged rock closure structures look similar to offshore rock mounds used for shoreline stabilization, they are usually constructed wider:

- The additional rock results in better self-healing capabilities in the event that toe scour causes some sloughing off the downstream side of the structure.
- A structure that has a width of about 12 feet at the water line presents the potential for construction access across the structure.
- A wider structure provides greater resistance against ice damage

Side Slopes. Side slopes vary from 1V:1.5H to 1V:4H. If the potential for ice damage exists, a flatter slope is usually used to increase the chance that ice will deflect up and over the structure.

Construction Material

Rock. Since most closure structures are designed to be overtopped, they can experience significant hydraulic forces during flood events and therefore are usually constructed of rock. The rock gradations used for closure structures in the St. Paul District are given in table 5.2. The standard gradation, which is similar to ASTM R-60, was established based on ease of obtaining it from quarries and the requirements for overtopping hydraulic forces. The large gradation has been used on several projects where ice action was expected to be a problem. It has also been used to discourage people from moving rocks. 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.

The highest benthic invertebrate density, biomass, and number of taxa were found in gravel substrate, samplers yielded nearly 27 times the number of macroinvertebrates than Ponar grab samples did from predominantly sand substrate near the dikes. Hall, Thomas J. 1980. *Influence of Wing Dam Notching on Aquatic Macroinvertebrates in Pool 13, Upper Mississippi River; The Pre-notching Study,* M.S. Thesis, University of Wisconsin, College of Natural Resources, Stevens Point, Wisconsin.

Table 5.2. Rock Gradations Used on HREP Projects

MVP	**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

MVR	**50#**	**150#**	**400#**	**600#**	**1000#**
100%	50-30	150-90	400-250	600-350	1000-650
50%	25-10	70-35	175-90	270-135	450-225
15%	6-2	20-7	50-15	70-20	125-40

MVS Rock Gradations Used on HREP Projects							
GRADED STONE A	100%	70-100%	40-65%	20-45%	0-15%	0-5%	
	5000#	2500#	500#	100#	5#	1#	
not more than 5% by weight finer than 1/2" screen							
GRADED STONE B	100%	72-100%	40-65%	20-38%	5-22%	0-15%	0-5%
	1200#	750#	200#	50#	10#	5#	<5#
GRADED STONE C	100%	70-100%	50-80%	32-58%	15-34%	2-20%	0-5%
	400#	250#	100#	30#	5#	1#	<1/2" max dimension
5% of the material can weigh more than 400 lbs. However no piece shall weigh more than 500 lbs.							

Earth. Experiments with vegetated earth closures, during the early years of the HREP program, were only partially successful, with several complete failures occurring. Because of this closure, structures are usually constructed of rock in the current program. If an earth structure is the best option, then the following engineering considerations should be considered.

- Adequate rock protection on the side slopes and possibly the top of the structure.

- Topsoil and vegetation should be established on the structure in places where rock is not used.

- A rock lined overflow section that is at a lower elevation than the remainder of the earth closure should be considered. This decreases the water surface differential over the earth portion of the structure during floods.

Woody Structure. Trees and brush can be anchored to the bottom of a channel to cause sediment deposition to occur. This borrows on the technique that was developed over a hundred years ago, when pile dikes were constructed to develop a navigation channel. Sand transported along the channel settled in the piles due to increased friction and decreased current velocities further increasing the effectiveness of the structure. The main requirement for these structures to work is an adequate sediment load, which isn't always the case in the northern pools of the UMRS.

Scour Hole Considerations. Although significant scour holes can develop on the downstream side of closure structures, these have rarely caused a significant problem for structure integrity. Usually the structures are constructed with enough rock so that some self-healing can occur and even if there is some sloughing on the downstream side of the structure, most of the crest of the structure remains at the design elevation.

5.2.1B. Design Methodology: Submerged Closure Structures. Submerged secondary channel closures (i.e. those with a top elevation less than the low water surface elevation) may take the form of underwater rock sills that are higher than the bed of the channel, or they may consist of a rock liner whose purpose is to stabilize the channel and prevent further erosion and enlargement. Engineering considerations regarding elevation, width, and side slope are similar to those for emerged structures and will not be repeated here. Calculating the flow over submerged structures is important, since they continuously convey water during all flow conditions. Safety for recreational craft is another consideration, since the location of these structures is not apparent to inexperienced boaters. Usually an elevation resulting in a depth of at least four feet during low flow conditions and a bottom width of 20 to 30 feet is specified based on recreational concerns.

5.2.2. Lessons Learned. The environmental objectives are applicable to all dike or closure designs, construction, and maintenance. These are:

- schedule construction and maintenance to avoid peak spawning seasons for aquatic biota.
- design and maintain dike fields to prolong the lifetime of the aquatic habitat (i.e., reduce sediment accretion).
- maintain abandoned channels open to the river.
- self adjusting rock is important to heal scouring should that develop.

5.2.3. References

Rock Island District Internet, EMP Habitat Rehabilitation and Enhancement Projects http://www.mvr.usace.army.mil/EMP/hrep.htm

US Army Corps of Engineers, St. Louis District, *Environmental River Engineering on the Mississippi* http://www.mvs.usace.army.mil/engr/river/EnvironEng/en01.htm

Environmental Guidelines for Dike Fields, Carey W. Burch, WES, Corps of Engineers, Vicksburg, Mississippi, September 1984.

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Waterways Experiment Station Report HL-81-3 *Channel Control Structures for Souris River, Minot, ND* 1981

Waterways Experiment Station Technical Report 2-650, *Stability of Riprap and Discharge Characteristics, Overflow Embankments, Arkansas River, Arkansas*. 1964

Yarnell, D.L. and F.A. Nagler (1930.) *Flow of Flood Water Over Railway and Highway Embankments.* Public Roads, Vol 11,No. 2.

Journal of the WATERWAYS AND HARBORS DIVISION, *Proceedings of the American Society of Civil Engineers, Research for River Regulation Dike Design.* John J. Franco, WES Research Hydrologic Engineer, August 1967.

5.2.4. Case Studies

Lake Chautauqua. A rock-filled channel entrance closure structure was constructed at Liverpool Ditch with the top elevation at flat pool to minimize future side channel sedimentation by preventing excessive diversion of river flows. Feature included 15 foot wide boat access with a water depth at flat pool of 3.5 feet. Photograph 5.2 shows in a chute between Liverpool Ditch and the pump station.

Bertom and McCartney Lakes. Rock closing structure to prevent bed load from entering the backwater

Peoria Lake. Rock dike constructed between constructed island and barrier island.

Gardner Division. A closing structure was constructed as part of this project to stop bed flow sediment from filling backwater areas.

Photograph 5.2. Rock Closure Structure and Illinois River (August 2004)

Weaver Bottoms, Pool 5. Rock and earth closures were constructed to reduce flow into the Weaver Bottoms backwater and the Lost Island Lake backwater. The earth closures were not overtopped until the 1993 flood, and the vegetation that had grown on them added to their stability. Two of the rock closures were lowered to increase conveyance of floodwater over the top of them.

Island 42, Pool 5. A layer of rock fill was placed along the main channel side of the earth closure across the inlet channel at an extremely steep slope (steeper than 1V:1.5H). During the 1997 flood this rock fill layer failed exposing bare earth. The mechanism was probably toe scour. Remedial action involved placing rock fill at a 1V:2.5H slope.

Weaver Bottoms, Pool 5. Rock and earth closures were constructed to reduce flow into the Weaver Bottoms backwater and the Lost Island Lake backwater. The earth closures were not overtopped until the 1993 flood, and the vegetation that had grown on them added to their stability. Two of the rock closures were lowered to increase conveyance of floodwater over the top of them.

Island 42, Pool 5. A layer of rock fill was placed along the main channel side of the earth closure across the inlet channel at an extremely steep slope (steeper than 1V:1.5H). During the 1997 flood this rock fill layer failed exposing bare earth. The mechanism was probably toe scour. Remedial action involved placing rock fill at a 1V:2.5H slope.

Pool 8, Phase I, Stage II (Boomerang). The entrance to Benover Slough was re-positioned to reduce the conveyance of sediment into the downstream backwater. Because water surface profile weren't being changed, the cross sectional area of the new entrance was sized to equal the area of the old entrance. Post-project surveys indicated that this method resulted in similar discharge rates through the slough for pre- and post-project conditions.

Indian Slough, Pool 4. This rock partial closure structure has been stable. The original slough has aggraded with sand as it adjusts to the reduced flow through this structure. The riffle pool structure, which consisted of two submerged rock weirs, has increased bathymetric diversity.

Polander Lake, Stage I, Pool 5A. A large rock closure was constructed across a secondary channel that entered Polander Lake. This structure has been stable since construction.

Lansing Big Lake. Earth closures were severely eroded during high water in the spring of 1995, and were replaced by rock closures in 1996. Shading by adjacent trees limited the growth of vegetation on the earth closures making them more vulnerable to erosion.

An earth dike was breached in several locations during high water in the spring of 1995, causing erosion down to the original substrate. The PDT had tried to limit the loss of floodplain trees leaving trees very close to and in a few cases within the footprint of the dike. The shading by these trees limited growth of vegetation on the earth dike making them more vulnerable to erosion. Eddy action around trees adjacent to the dike also resulted in scour, though not a complete breach. These breaches were filled with a layer of riprap to create an overflow section. The elevation of the overflow section was lower than the elevation of the remaining earth dike so that flow would occur over the overflow section first reducing the head differential when the earth dike was overtopped. This has resulted in a stable structure that has been overtopped several times.

Spring Lake, Pool 5. This closure structure has been stable. An earth closure was constructed across a breach in the natural levee separating Spring Lake from an adjacent channel. The shorelines of this structure were stabilized with riprap at a 1V:3H slope on the channel side and 30’ long rock groins on the Spring Lake side. Native grasses were planted along the top of the structure in 12 inches of topsoil.

Peterson Lake. Earth closures that were constructed across three small channels at the upper end of Peterson Lake were severely eroded during high water in the spring of 1996. These were replaced by rock structures that were set at a lower elevation than the adjacent channel banks. These structures have been relatively stable, though some remedial work has been required to patch small breaches at the point where the rock structures tie into the adjacent bank.

The submerged and emerged rock structures that were constructed as part of the original project have been stable.

Rice Lake Minnesota River. The earth berm with a lower overflow spillway section constructed of rock has been stable since island construction in 1996.

Long Lake, Pool 7. The earth berm constructed across the excavated channel into this lake was completely eroded during the 2001 flood. This caused the concrete water control structure to be undermined. As part of the repair of this project, a rock lined overflow channel was constructed to help decrease the head differential across this structure during flood events.

Pool 8 Islands, Phase II. Although this is primarily an island project, two rock sills, which essentially act as closure structures were constructed. Rock sill top widths were set at 13’ in case a scour hole developed downstream of the rock sill. The thought was that if scour started under-mining the downstream toe, the sill would be wide enough for some self-healing to occur without losing the entire crest of the structure. However, field reconnaissance indicates that scour has not occurred at these rock sills. The rock sill top width probably could have been 10’ and perhaps even less.

The upstream slope of the sills was set at 1V:4H because of a concern with ice action. The flatter slope should result in ice riding up and over the structure rather than displacing rock.

Morgan Point Bendway Closure Structure, Arkansas. The $2.7 million project was designed to restore flows to the Morgan Point Bendway, which was cut off when the Wilbur D. Mills Dam was constructed. An overflow weir closure structure at the mouth of the bendway and a water supply pipeline from the dam was built. Additionally, some areas of the shoreline were planted with cypress, and fish shelters were placed in the bendway. Approximately 7 miles of riverine habitat were restored, resulting in 966 surface acres of aquatic habitat, of which 202 acres will be emergent wetlands.

5.3. Wing Dams (Notching)

Figure 5.1. Wing Dam Notching

5.3.1. Design Methodology. Rock dikes, running perpendicular to the shore, have long been used to guide the river and maintain the navigation channel. River engineers found that simply by adding notches, the dikes continue to create navigation dimensions as well as support diverse habitats. Figures 5.1 and 5.2 show an example of notching.

The river is allowed to move in and out between the notches creating all four of the primary river habitats. Sediment buildup forms small sandbars between each of the dikes. A variety of notch locations, sizes and widths can be used to create the optimum design. The overall result, however, is the creation of diverse environments by making a small but significant design modification.

The diversity of fish communities has been found to be slightly higher at notched dikes. The diversity of aquatic invertebrate was significantly greater at notched dikes. This seemingly can be attributed to the greater variety of habitat created below notched structures. The creation of small chutes within a dike field, the presence of submerged sandbars, and increased edge habitat are valuable forms of aquatic habitat diversity that benefit not only the fish community, but the macroinvertebrate community as well. The highest benthic invertebrate density, biomass, and number of taxa were found in gravel substrate …samplers yielded nearly 27 times the number of macroinvertebrates than Ponar grab samples did from predominantly sand substrate near the dikes. (Hall)

Removed material placed downstream of the notch creates interstices and promotes invertebrate colonization, thus promoting fish foraging. Flow will increase in the vicinity of the notch, deepening the pool behind the wing dams. The change in flow at one wing dam may also stimulate an in-stream meander to the next wing dam. A meander would create deeper areas, attracting a more diverse benthic community and fishery. In technical report E-84-4 titled, Environmental Guidelines for Dike Fields, by Carey Burch, et al. (1984), notching emergent wing dams resulted in holes being eroded in the sediment downstream of the notch. The wing dams in their study extended from the channel bottom to above normal water level (i.e., emerged wing dams).

The St. Paul District has experimented with wing dams for the purpose of creating scour holes on the downstream side. It is anticipated that the increased bathymetric diversity was found to be more discernible where larger notches were constructed and where the wing dams extended above the surrounding river bottom a few feet as opposed to those locations where the wing dams were nearly flush with the surrounding river bottom.

In some locations that could be characterized as generally depositional in nature, the notches in the wing dams are not discernible, indicating the notches may have been filled in the spring 2001 flood.

There may be a great deal of bed load moving through some of these main channel border areas. These areas are effectively sandbars that are relatively unstable, depositing in one year or one part of the hydrograph and eroding during the next year or another part of the hydrograph. Scour holes and other bathymetric diversity that develops in these areas may be temporal in nature.

The period of record is relatively short – 2 years between the notchings and the post-notching surveys. The changes may have been developed during the flood of 2001 and it may take additional time for any changes produced by the notches to be evident, Jon Hendrickson, MVP 2005.

The following steps are suggested for design of notches.

A. Study the design of notches in locations similar to the site in question. If no notches have been constructed in similar locations, perhaps there are a few failure notches.

B. Determine which dikes to notch

1. Omaha District recommends that: large numbers of structures over long reaches be modified rather than conducting intensive notching in isolated localities; notches should not be placed near structures such as cabins or pipeline crossings where small amounts of bankline erosion or bed scour might cause problems; notches in spur dikes are generally more effective than notches in longitudinal dikes in terms of developing open water; notches in pairs or series are frequently effective, with upstream notch and backwater serving as a settling basin for downstream areas; and L-head dikes constructed just upstream from tributary inflows should be notched to prevent sediment buildup at the tributary mouth. (Burch 1984)

2. Smith et al. (1982) noted that both notched and un-notched structures provide habitat for distinct assemblages of fish. Therefore, not every dike should be notched.

3. If a large number of notches are to be constructed, locations notched first should be those where notches tend to produce the best habitat.

C. Determine the location of the notch on the dike. Notches should be far enough from the bankline to prevent flanking problems. The distance from the notch to the riverward tip should be varied to diversity.

D. Select notch width. Wide notches are less susceptible to debris blockage. However, in some cases, increased width tends to reduce scour downstream of the notch. In general, notch width should be 10-25 percent of the riverward length of the structure. Notches must be wide enough to develop desirable habitat, yet not wide enough to induce damaging erosion, structural failure, or undesirable effects on the navigation channel. Notch width should increase with dike angle.

E. Select notch shape and depth

1. Notches may be either trapezoidal or triangular. Flow through a triangular notch is a stronger function of depth than flow through a trapezoidal notch.

2. Extremely deep notches are effective at developing a downstream scour hole and high velocities. However, once the scour hole is formed, lower velocities and resultant finer grained substrate are more desirable from a habitat standpoint (Smith et al. 1983). In some cases it may be advantageous to construct deep, wide notches at first and partially close them after some initial development.

3. Omaha District (1982) recommends two alternative philosophies for selecting notch depth: either choose a depth that will allow flow almost all of the time, or choose a depth that will is only overtopped at moderate and higher stages, thus providing slack water at lower stages. Deep notches are recommended for locations with wide stage fluctuations. Use of a variety of notch dimensions throughout a reach will provide habitat diversity with changes in stage.

F. If notches are to be excavated in existing structures, select a method for disposal of excavated stone. Alternatives include piling the stone in the dike field to develop aquatic habitat, using the stone for ongoing maintenance, or stockpiling for future maintenance.

5.3.2. Lessons Learned

- Rock size spec as 400-lb. or larger rock, considering potential for interstitial spaces for critters or vary rock spec with expected hydraulic flow conditions v. sedimentation rates.
- Sizing/designing notches and other structures to naturally create plunge pools at higher flows that would provide 6 to 8 feet of deeper, stiller water during the normally lower flows more typical during overwintering periods.
- Monitor enough mussel beds upstream or downstream of wingdams being notched to satisfactorily assess and evaluate the extent of impacts, if any, on mussel abundance and diversity in the bed before and after notching.
- Various styles of notches and their bathymetric effects were studied by Brown in a laboratory.

5.3.3. References

USACE, St. Louis District, *Environmental River Engineering on the Mississippi* http://www.mvs.usace.army.mil/engr/river/EnvironEng/en01.htm

RI District Internet, EMP HREPhttp://www.mvr.usace.army.mil/EMP/hrep.htm

Hall, Thomas J. 1980. *Influence of Wing Dam Notching on Aquatic Macroinvertebrates in Pool 13, Upper Mississippi River; The Pre-notching Study*, M.S. Thesis, University of Wisconsin, College of Natural Resources, Stevens Point, Wisconsin.

Brown, J.L., et al., *Generic Dike Flume Study*, USACE, St. Louis District, 2005.

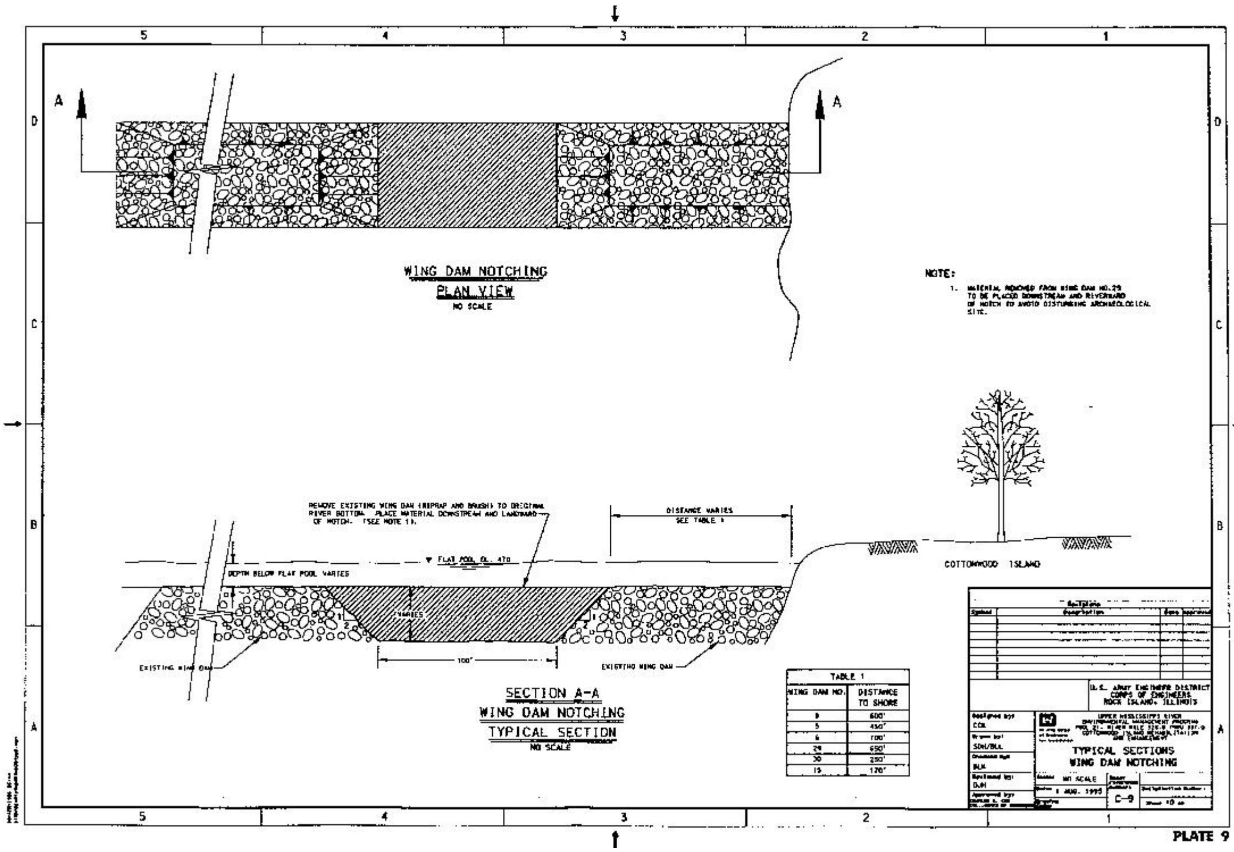


Figure 5.2. Wing Dam Notch

5.3.4. Case Studies

Cottonwood Island. Existing wing dams notched to create habitat between them

Hershey Chute. Hershey Chute Dredge Cut and Placement Site, Upper Mississippi River Miles 460.7 -461.8, Pool 16, Notched wing dams constructed

Dark Slough. Dark Slough Dredge Cuts, Pool 13, River Miles (RM) 531.0-531.3, Wing dams rebuilt and notched

Pool 12 Overwintering. A small wing dam will be constructed in a side channel to maintain depth in an entrance to a backwater.

Six dikes near Upper Mississippi River Mile 100 were notched in the 1970s. Since notching, 5 islands have formed between the structures (figure 5.3).

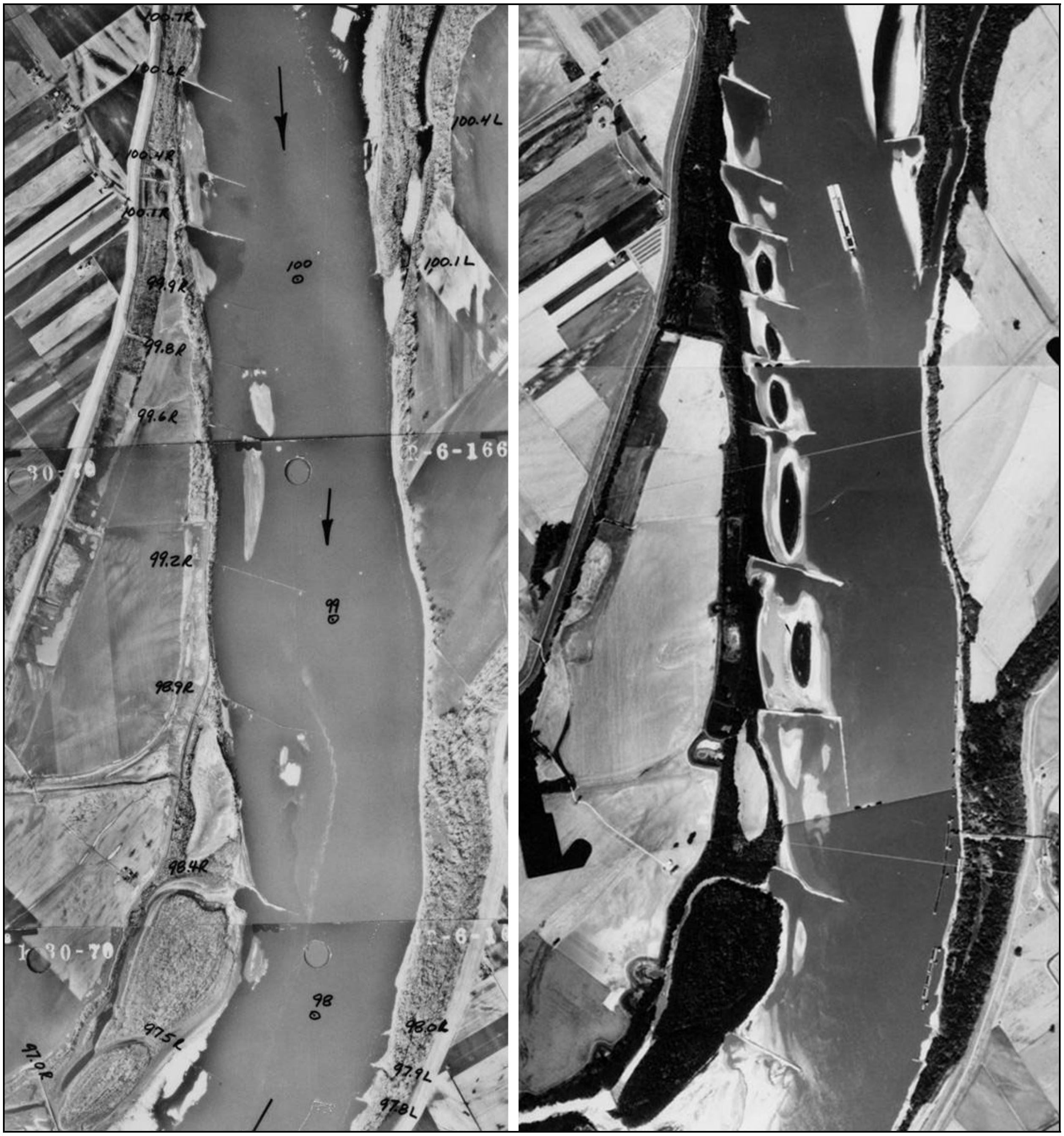


Figure 5.3. Mississippi River Wing Dam Notching

5.4. W-Weirs

5.4.1. Design Methodology

5.4.1.1. Rock Size. Rock used for the construction of W-weirs will meet the following size requirements, as shown in table 5.3. All units are shown in feet (ft) and pounds (lbs). Rock sizes apply to both Footer Rocks and Weir Rocks. The dry unit weight of each rock shall be 150 lbs/cu ft or greater.

Table 5.3. W-Weir Rock Size

	A-axis	B-axis	C-axis
Minimum Size	4'	3'	2'
Maximum Size	8'	6'	5'

5.4.1.2. Construction Methods

- W-Weirs shall be constructed with two (2) Rock Vanes on opposing sides of the stream channel forming the outside legs of the W-Weirs and two opposing vanes in the center of the channel to complete the W-Weir. W-Weirs may be staggered, such that one leg of the W-Weirs is offset either upstream or downstream of the opposite leg. The “W” shape is seen when viewing the W-Weirs from upstream looking downstream.

- The outside Rock Vane components shall extend to the streambed invert in an upstream direction forming the outside legs of the W-Weir. The inside legs of the W-Weir shall be constructed similar to a Rock Vane with the exception that the apex (joining point) of the inner legs is at an elevation that does not exceed one-half (½) of the bankfull elevation.

- The W-Weirs shall be constructed so that adjoining rocks taper in an upstream direction (outside legs) from the bankfull elevation to the stream invert. The inside legs shall extend from the streambed invert in a downstream direction and shall be tapered to a point one-half (½) the bankfull elevation. The elevation of the apex of the W-Weir may be adjusted as required or as directed by the Contract Officer/Project Engineer. The upstream end of the outside legs of the W-Weir is set at an angle of 20o-30 tangent to the curve.

- The downstream end of the outside legs of the W-Weir shall be keyed into the streambank at the bankfull elevation. The W-Weir shall be keyed a minimum of eight feet (8') into the streambank. The upstream end of the outside legs as well as the upstream end of the inside legs, will be keyed into the streambed at the invert elevation. The W-Weir legs shall be installed with a slope of 4% to 7% from the streambed invert to the bankfull or apex elevation.

- Footer Rocks shall be installed as shown in the Plans and Details and shall be firmly keyed into the streambed. All W-Weir rocks shall be placed behind footers. On larger streams, double footer rocks may be required to insure that the footer extends below the final invert of the plunge pool associated with the W-Weir.

- Rocks placed to construct the legs of the W-Weir shall be placed in a linear fashion so as to produce a sloping surface. Rock shall be placed with a tight, continuous surface contact between adjoining rock. Rock shall be placed so as to have no significant gap between adjoining rock.

- Rock shall be placed so as to have a final smooth surface along the top plane of the W-Weir. No rock shall protrude higher than the other rock in the W-Weir leg. A completed W-Weir has a smooth, continuous finish grade from the bankfull elevation to the streambed, and from the streambed to the apex.

- Upon completion of the W-Weir, the Contractor shall place stabilizing vegetation as shown in the Vegetation Plan and Specifications.

- The Contractors shall upon completion of the work reshape the slopes and stream bottom to the specified elevations. All unsuitable and surplus rocks will be removed from the site.

5.4.2. Lessons Learned . None listed.

5.4.3. References

"Greene County Soil & Water Conservation District", Stream Restoration Program webpage, Stream Restoration Library construction specification SR-04. http://www.gcswcd.com/stream/library/pdfdocs/sr-02.pdf

5.4.5. Case Studies. None listed.

5.5. Notched Closure Structures

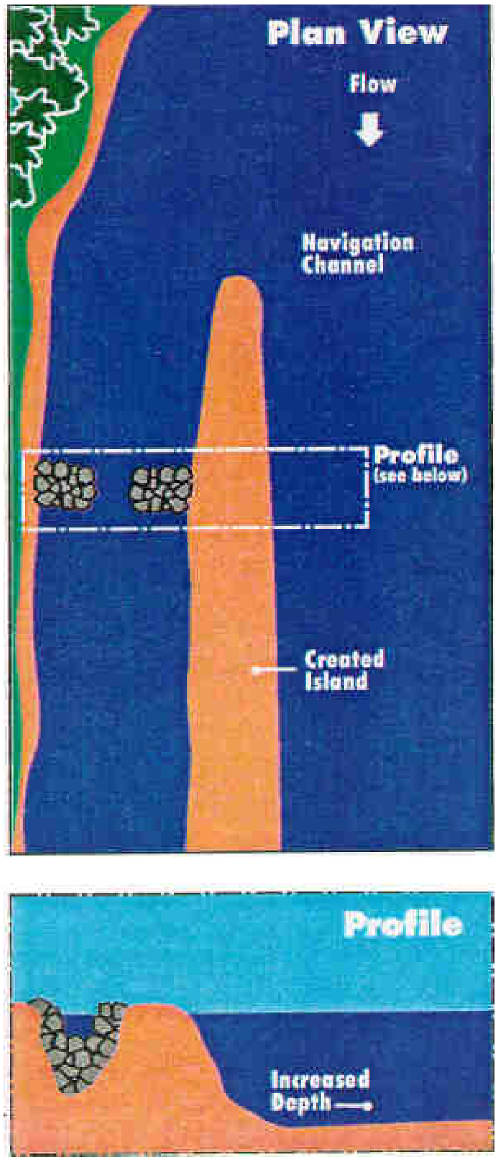


Figure 5.4. Notched Closure Structures

5.5.1. Design Methodology . Side channels are not used for navigation, but are valuable environmental areas. Traditionally these side channels were closed with rock structures to divert the flow into the main channel. While improving navigation, this process tends to fill the side channels with sediment and convert aquatic habitat to terrestrial habitat.

Notching a closure structure tends to keep the side channels from being filled with sedimentation. These structures form areas of deep water and shallow water creating a diversity of habitat, attracting different species of fish. (figure 5.4).

5.5.2. Lessons Learned . None listed.

5.5.3. References

US Army Corps of Engineers, St. Louis District, *Environmental River Engineering on the Mississippi*, web site. http://www.mvs.usace.army.mil/engr/river/EnvironEng/en01.htm

Rock Island District Internet, *EMP Habitat Rehabilitation and Enhancement Projects* http://www.mvr.usace.army.mil/EMP/hrep.htm

Green County, New York Soil & Water Conservation District, Stream Restoration Library, http://www.gcswcd.com/stream/library/

5.5.4. Case Studies

US Army Corps of Engineers, St. Louis District, Marquette Chute, near Middle Mississippi River Mile 51.0L.

5.6. L-Head Dikes

Photograph 5.3. L-Head Dike, Marquette Chute, near Middle Mississippi River Mile 51.0L

5.6.1. Design Methodology . The L-Head is a training dike with a perpendicular dike structure attached at the channel end creating an L shape. The attached dike structure is usually lower in elevation (e.g. 1-5 feet). The purpose of this structure is to control scour patterns at the training dike's riverward end for channel improvement. Photograph 5.3 shows an example.

Dike fields are constructed to change the morphology of natural alluvial waterways. Dike fields accomplish this by stabilizing the position of bars, controlling flow through secondary channels, and reducing channel width over some range of discharges. Dike fields are normally used in conjunction with revetments to develop and stabilize the channel.

Dike fields change river morphology by decreasing the channel width in the vicinity of the dike fields, decreasing the surface area of the waterway, increasing the depths through bed degradation, and sometimes shifting the channel position. As the flow is realigned and/or constricted, the bed is scoured by locally higher velocities. Decreased velocity within the dike field leads to accretion of sediment in this area.

Effects of low-elevation dikes on habitat diversity occur through changes in water depth and sediment characteristics. These changes are determined by the behavior of the flow over the crests of the dikes. Local flow accelerations have been observed over submerged dikes. These accelerated flows usually develop a scour hole immediately downstream of the dike with a submerged bar forming downstream of the hole (Burke and Robinson 1979). Lower elevation dikes tend to accrete larger sediment deposits within the dike field than higher elevation dikes. However, it has been found that the higher the dike, the more rapidly secondary channels and backwaters filled with sediment and the more rapidly a bar was produced below the dike. The location has more influence on the rate and extent of sediment accretion than dike design. A dike built in a zone of deposition will be likely to accrete sediment regardless of its crest elevation.

Low elevation dikes have beneficial impacts on habitat diversity through the creation of the deep scour holes. These holes provide important shelter for fish during the winter low-flow season. The submerged sandbars provide shallow-water habitat which provides nursery areas for many fish species. The Environmental Work Team (1981) found smallmouth bass, northern pike, and walleye associated with submerged dikes on the upper Mississippi River. Dikes less than 5 ft in depth (corrected to operating pool levels) had significantly higher fish catch than deeper dikes. Dikes on concave sides of bends had significantly higher catch and number of species than dikes on convex sides of bends.

5.6.2. Lessons Learned. Adverse effects are related to sediment accretion, alterations in river depth and stage, reduction in wetted edge, locally increased main channel velocities, and a reduction in slack water habitat caused by closure and subsequent sedimentation of sloughs, chutes, and secondary channels.

5.6.3. References

US Army Corps of Engineers, St. Louis District, *Environmental River Engineering on the Mississippi*, web site. http://www.mvs.usace.army.mil/engr/river/EnvironEng/en01.htm

5.6.4. Case Studies

Kansas River at Eudora Bend, KS

Monkey Run at Arcade, NY

Eighteen Mile Creek salmon stream restoration, Newfane, NY

5.7. Spur Dikes

5.7.1. Design Methodology. These structures are used in river training as contraction works to establish normal channel width; to direct the axis of flow; to promote scour and sediment deposition where required; and to trap bedload to build up new banks. Although less effective than training walls in rivers carrying small bedloads and in channels having steep gradients and swift currents, they are often more economical than longitudinal works since material is required to protect the bank. The engineer must rely on experience and know-how in using these structures. Figure 5.5. shows an example of spur dikes.

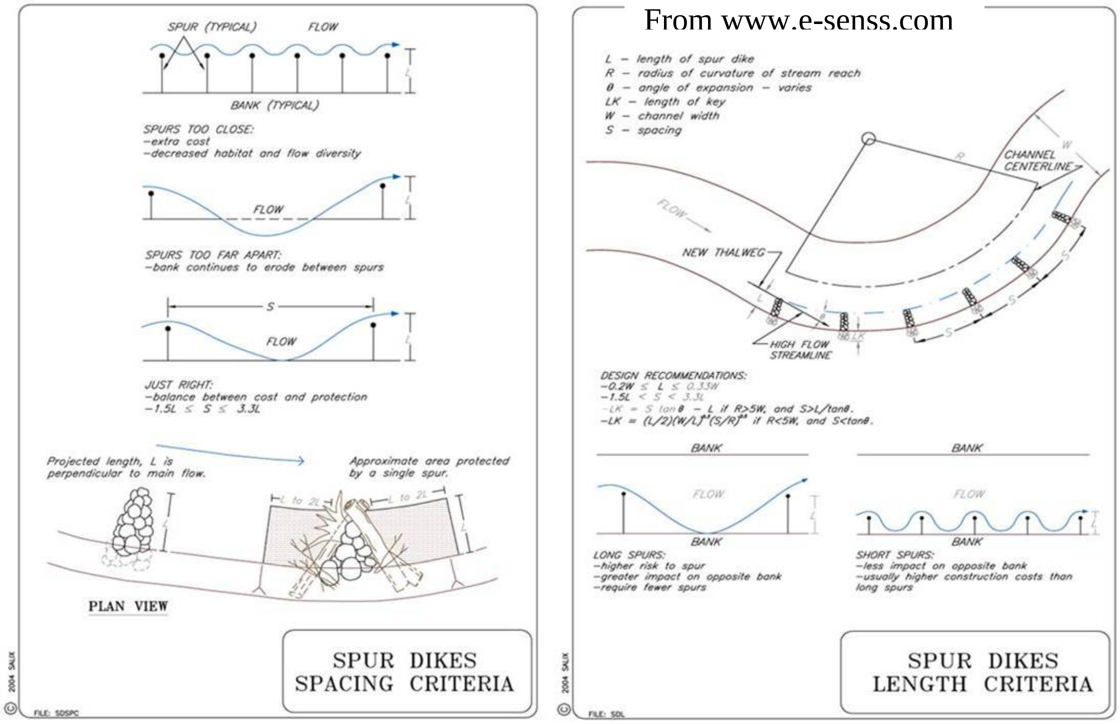


Figure 5.5. Spur Dikes

The general practice in design and construction of spur dikes has been to place the crest of each dike in a system at about the same elevation with respect to a low-water profile and position most of the dikes in a system generally normal (perpendicular) to flow.

WES evaluated dike performance and released the results. Some parameters considered in the development of the rating system were as follows:

- Controlling Depth - The least channel depth available along the thalweg in the reach is referred to mean low water, and indicates the maximum draft of a tow which could navigate the reach. Controlling depth would be a measure of the effectiveness of the dike in producing the channel depths required. Measurement of increase in controlling depth in feet below that existing without the structures.

- Channel Alignment – The alignment of the sailing line in which would have to be followed by a tow having a draft equal to the controlling depth, indicating the degree of maneuvering required to navigate the reach. The alignment a channel could be such that long tows (1200 ft and longer) could negotiate the turns required. Value of 3.0 for excellent, 2.5 for good, 1.5 for fair, and none for poor.

- Dredging – Amount of material to be removed to provide project depth along a reasonably good channel alignment. The amount of dredging required to produce the required channel dimensions is not necessarily indicated by the controlling depth. The amount of reduction in dredging index (1,00 cu yd per foot channel width) required to produce a channel of project depth based on that required without the structures.

- Maximum Scour – Maximum scour usually occurs at the channel end of dikes. It provides an indication of a dike's obstruction of flow, head loss at the dike, reinforcement needed near the ends, and maintenance requirements. Value obtained when elevation when elevation of the dike, in feet mlw, is divided by the depth of scour referred to mlw. Scour is related to the elevation of the dike in this rating system to prevent low dikes, which normal produce less scour from being given a rating of such value that it might offset other more serious deficiencies.

- Deposition Below Dikes – An indication of the effectiveness and permanency of the structure is provided by the deposition below the dikes. It is probably more important with permeable type dikes which depend on the material deposited behind them for the degree of contraction provided. The effective height of rock dikes could be increased by deposition sufficient to promote the growth of willows. *Deposition is based on average of the maximum elevation below each dike related to the average elevation of the dikes, and may be given*

$$\textit{Deposition} = \frac{\textit{Average elevation of maximum deposition below each dike in feet mlw;}}{\textit{Sum of average elevation of each dike divided by number of dikes}}$$

- Dike Elevation – Dike elevation is an indication of the amount of rock required for construction per unit length. Because of side slope, the rate of increase in rock required is greater than the rate of increase in height of dike. *Channel Cross-Sectional Area and Dike Elevation – The cross-sectional area as affected by the dikes and the elevation of the dikes are not considered in the rating system. In this study, the cross section was not changed except as affected by differences in dike elevation. Dike elevation will tentatively be considered as a description of the dike system and an indication of relative cost. To provide an indication of the relative cost, the average elevation of a dike system is considered as*

$$\textit{Average Elevation of dike system} = \frac{\textit{Sum of average elevation of each dike times length of dike}}{\textit{Total length of all dikes in system}}$$

- Channel Cross-Sectional Area – The degree of contraction effected by the dikes could be expected to have an effect on the performance of the dyke system. This would ordinarily determine the length and position of dikes rather than type of dike structures. In streams not fully canalized, the change in cross-sectional area caused by the

> construction of dikes would not necessarily be an indication of the degree of contraction produced by dike. In such cases, current directions and velocities in the reach before the installation of the dikes would provide a better indication of the probable effects of the dikes on flow, since dikes placed in slack water or low-velocity areas would not be as effective in higher velocity currents. Also, it must be considered that the degree of contradiction would change with river stages. See section on Dike elevation above.

In tests with varied longitudinal profiles, the system with the lowest average elevation had the best performance rating. When a dike is low with respect to the next dike downstream (stepped-up profile), at least some of the flows over the top of the lower dike has to move channelward, producing disturbances because of its direction. The flow tends to prevent sediment-carrying bottom currents from moving into the area between the dikes. With a system where the elevation of each succeeding downstream dike is lower, flow from the channel moves around the end of the high dike into the area behind the high dike toward the next lower dike. The faster moving surface currents continue in a relatively straight line while the slower, sediment-carrying bottom currents move into the dike field.

For sloping-crest dike system testing, bank ends were maintained at the same elevation and the river elevations were varied. Because of variation in dike length, a stepped-down effect was not produced by stepping-down the ends. The dike system with the lowest average elevation had a performance rating about 80% higher than the other systems. There appeared to be little difference in the performance of the other two systems, ends stepped up and ends level. Tables 5.4, 5.5, 5.6, and 5.7 compare three systems.

Table 5.4. Comparison of Performance of Three Profiles

Factors	Crest Level Profile Level		Crest Level Profile Stepped-Up		Crest Level Profile Stepped-Down	
	Performance	**Rating**	**Performance**	**Rating**	**Performance**	**Rating**
Increase in depth, in feet	6	6.00	7	7.00	7	7.00
Channel Alignment	Excel	3.00	Poor	0.00	Good	2.50
Dredging Index	0.04	3.29	0.22	3.11	0.07	3.26
Maximum scour, elevation	-54	0.28	-45	0.33	-52	0.29
Deposition (average elevation)	13.0	0.87	7.0	0.56	12.3	0.99
Total Rating		**13.34**		**11.00**		**14.04**
Avg dike elevation	15.0		13.1		11.9	

Table 5.5. Comparison of Performance of Three Systems

Factors	Ends stepped-Up		Ends stepped-Down		Ends Level	
	Performance	**Rating**	**Performance**	**Rating**	**Performance**	**Rating**
Increase in depth, in feet	3	3.00	7	7.00	3	3.00
Channel Alignment	Fair	1.50	Good	2.50	Fair	1.50
Dredging Index	0.79	2.54	0.01	3.32	0.86	2.47
Maximum scour, elevation	-40	0.38	-47	0.32	-38	0.33
Deposition (average elevation)	4	0.32	10	0.83	6	0.48
Total Rating		**7.74**		**13.97**		**7.78**
Avg dike elevation	13.1		11.9		12.5	

Table 5.6. Performance of Three Alignments

Factors	Angle of Level-Crest Dike System					
	Normal		**30º Upstream**		**30º Downstream**	
	Performance	**Rating**	**Performance**	**Rating**	**Performance**	**Rating**
Increase in depth, in feet	6	6.00	6	6.00	7	7.00
Channel Alignment	Excel	3.00	Fair	1.50	Excel	3.00
Dredging Index	0.04	3.29	0.25	3.08	0.08	3.25
Maximum scour, elevation	54	0.28	42	0.36	47	0.32
Deposition (average elevation)	13	0.87	12	0.80	13	0.87
Total Rating		**13.44**		**11.74**		**14.44**
Avg dike elevation	15.0		15.0		15.0	

Table 5.7. Effect of Dike Elevation in Controlling Depth

Dike System	Increase in Controlling Depth, in feet		
	Highest Dikes	**Intermediate Dikes**	**Lowest Dikes**
Level-level (normal)	6.0	3.0	2.0
Level-level (angled downstream)	7.0	2.0	1.0
Stepped-down (normal)	7.0	6.0	2.0

5.7.2. Lessons Learned

- Spur Dike spacing is critical. If the spacing is to close, the depositional areas will not form and if the spacing is too far, bank erosion is possible between the structures.

- An important factor to be considered in dike design is the movement of currents near and within the dike field.

- Dike systems having the stepped-down effect are more effective than dike systems with all dikes level. Dikes constructed with their crests level with respect to each other are more effective than dikes having the stepped-up effect.

- Sloping-crest dikes can be designed to be as effective as level-crest dikes.

- The amount of dredging required to produce project dimensions is inversely proportional to dike elevation.

- There is a greater tendency for dikes angled downstream to be flanked near the bank end than dikes angled upstream, and for level-crest dikes to be flanked near bank end than sloping-crest dikes.

- Level-crest dikes should be placed normal to the flow or angled downstream. Sloping-crest dikes should be placed normal or angled upstream.

- Channel width influences the use of bendway weirs and other spur-type countermeasures. On smaller streams (<75 m (250 feet) wide), flow constriction resulting from the use of spurs may cause erosion of the opposite bank. However, spurs can be used on small channels where the purpose is to shift the location of the channel.

5.7.3. References

Derrick, David, L. (2005): *#6 Re-directive-Compressed*

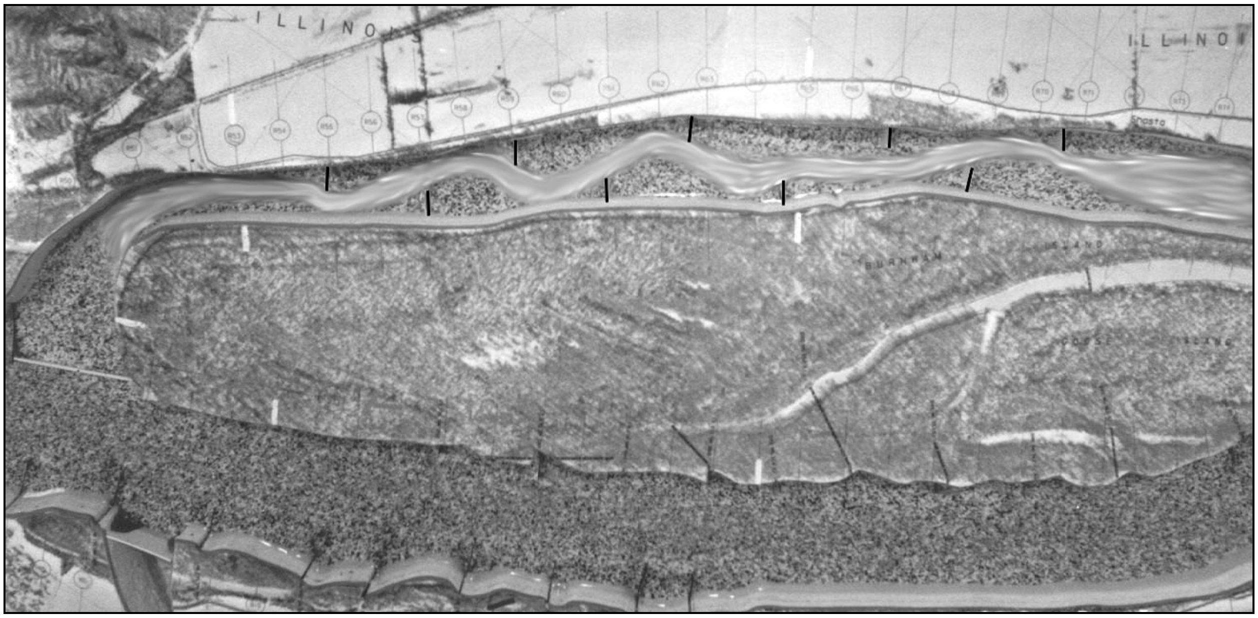
Journal of the WATERWAYS AND HARBORS DIVISION, *Proceedings of the American Society of Civil Engineers, Research for River Regulation Dike Design.* John J. Franco, WES Research Hydrologic Engineer, August 1967.

5.7.4. Case Studies

Little Blue River, Marysville, KS

5.8. Alternating Dikes

5.8.1. Design Methodology. Alternating dikes can typically be used in side channels that are long and straight. The dikes are placed along both banklines in an alternating configuration. The design creates a sinuous flow pattern in areas that previously had homogeneous flow. The river bed is also altered with the development of scour holes off the ends of each dike and sand bars along the banklines upstream and downstream of each structure. Photographs 5.4 and 5.5 show examples of alternating dikes



Photograph 5.4. Alternating Dikes

Photograph 5.5. Alternating Dikes

The altered flow patterns typically put additional flow along the bankline, opposite each dike which could induce erosional tendencies. Therefore, these areas should be armored with stone if these banklines are privately owned, if infrastructure is present or if lateral movement of the bankline is simply not desired. If the land is publicly owned, lateral movement of the bankline could produce a sinuous planform if allowed to erode naturally.

The design of alternating dikes is usually initiated with the use of a micro model. The model is typically used to determine spacing, length, and height of each structure. Each dike is usually constructed to a maximum of 1/3 of the overall side channel width and is keyed into the bankline using standard design parameters for dike construction. Revetment is placed for a short distance both upstream and downstream of the structure to protect it from flanking. In some cases, revetment can be placed along the opposite bankline from the dike head to prevent channel meandering.

5.8.2. Lessons Learned. Most dikes built along the main channel border are typically ½ to 2/3 bankfull height. This elevation has proven to be an effective height to produce the desired riverbed scour and channel formation. However, most side channels in the Mississippi River flow less frequently and with less energy than the main channel. Bed elevations are usually much higher than the main channel. Dikes built in side channels to typical elevations used in the main channel have not always created the desired effects. Therefore, for maximum effectiveness, alternating dikes are typically constructed to an elevation close to the top-of-bank elevation. This elevation utilizes the maximum amount of energy available in the side channel during bankfull and flood flows to scour the bed and create the desired flow patterns.

5.8.3. References

Davinroy, R. D., Gordon, D. C., Hetrick, R. D., *Sedimentation Study of the Mississippi River, Sante Fe Chute, Doolan Chute, Hydraulic Micro Model Investigation,* U.S. Army Corps of Engineers, St. Louis District, September 1996.

Davinroy, R. D., Gordon, D. C., *Sedimentation Study of the Mississippi River, Schenimann Chute, Mississippi River Miles 63 to 57, Hydraulic Micro Model Investigation,* U.S. Army Corps of Engineers, St. Louis District, May 2000.

5.8.4. Case Studies. Sante Fe Chute was micro modeled in 1996 to study various methods of rehabilitation. This project is shown in photograph 5.6. After it was discovered that removing the closure structure at the upper end of the side channel would increase deposition in the chute, designs were considered that would make use of the existing energy in the side channel to create bathymetric diversity. It was discovered that alternating dikes could have a unique effect. Although it was recommended to construct 9 dikes at elevation top-of-bank only 6 dikes were constructed in 1997 to an elevation of ½ bankfull due to funding limitations.

After monitoring the riverbed, it was determined that although the design had shown some indication that it was producing the desired effects, it still was not what the designers had envisioned. Therefore, once adequate funding was received, the dikes were raised to the original design elevation and the remaining dikes were constructed. The side channel is now developing the bed forms originally predicted by the micro model. Scour holes are developing off the ends of the upstream dikes first as the bed development works in the downstream direction. Due to low frequency of flow in the side channel, the bed development has progressed slowly. The revetment along both banklines and adjacent the privately owned land is providing the necessary protection.

Photograph 5.6. Santa Fe Chute

5.9. Stepped Up Dikes

5.9.1. Design Methodology. Stepped-Up dike fields of various elevations were developed to provide an additional element of diversity. They counteract sediment deposition, thereby preventing the conversion of aquatic environment into terrestrial. In the stepped-up dike configuration, each dike in sequence rises two feet higher than the previous one. This approach utilizes the river's energy to change the sediment deposits as the water level rises and falls. (figure 5.6).

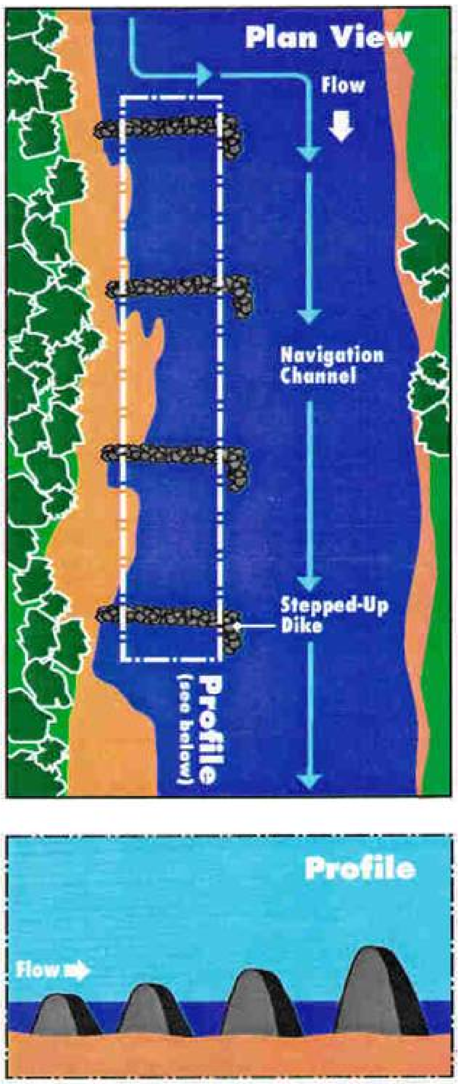


Figure 5.6. Stepped Up Dikes

Dike fields are constructed to change the morphology of natural alluvial waterways. Dike fields accomplish this by stabilizing the position of bars, controlling flow through secondary channels, and reducing channel width over some range of discharges. Dike fields are normally used in conjunction with revetments to develop and stabilize the channel.

Dike fields change river morphology by decreasing the channel width in the vicinity of the dike fields, decreasing the surface area of the waterway, increasing the depths through bed degradation, and sometimes shifting the channel position. As the flow is realigned and/or constricted, the bed is scoured by locally higher velocities. Decreased velocity within the dike field leads to accretion of sediment in this area.

Beneficial environmental effects are related to the diversity of substrates, depths, and velocities created by the dike fields and often provide a diverse habitat with a relatively high level of biological activity. Adverse effects are related to sediment accretion, alterations in river depth and stage, reduction in wetted edge, locally increased main channel velocities, and a reduction in slack water habitat caused by closure and subsequent sedimentation of sloughs, chutes, and secondary channels.

5.9.2. Lessons Learned. None listed.

5.9.3. References

US Army Corps of Engineers, St. Louis District *Environmental River Engineering on the Mississippi*, http://www.mvs.usace.army.mil/engr/river/EnvironEng/en01.htm

Rock Island District Internet, EMP Habitat Rehabilitation and Enhancement Projects http://www.mvr.usace.army.mil/EMP/hrep.htm

5.10. Bendway Weirs

5.10.1 Design Methodology. The Bendway Weir is a low level, totally submerged rock structure that is positioned from the outside bankline of the riverbend and angled upstream toward the flow. These underwater structures extend directly into the navigation channel underneath passing tows. Their unique position and alignment alter the river's spiraling, secondary currents in a manner which shifts the currents away from the outside bankline. This controls excessive channel deepening and reduces adjacent riverbank erosion on the outside bendway. Because excessive river depths are controlled, the opposite side of the riverbank is widened naturally. This results in a wider and safer navigation channel through the bend without the need for periodic maintenance dredging. The Bendway Weir also eliminates the need for dikes to be constructed on the inside of the bendway therefore protecting the natural beauty and habitat of this sensitive environment.

The Bendway Weirs have not only provided navigation benefits, but many significant environmental benefits have been achieved as well. A wider and more smoothly aligned navigation channel has resulted so that traditional above-water dikes will no longer be built on the sandbars. Nesting Habitat for the Least Tern, an endangered bird species is thus left largely undisturbed. Bendway Weir fields have also proven to provide habitat for a number of fish species. These environmental reefs have created diversity in the river bed and flow patterns in areas that were once narrow, deep, and swift. Monitoring efforts have shown that the federally endangered Pallid Sturgeon uses the weir fields significantly for their habitat. Figure 5.7 shows bendway weirs.

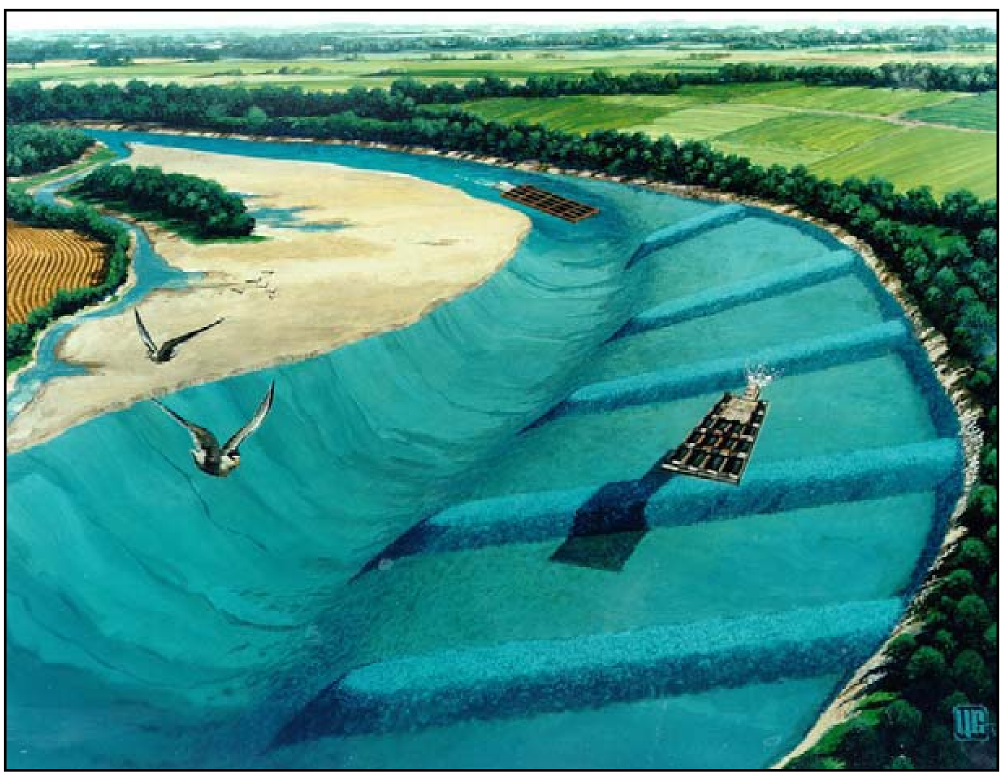


Figure 5.7. Bendway Weirs

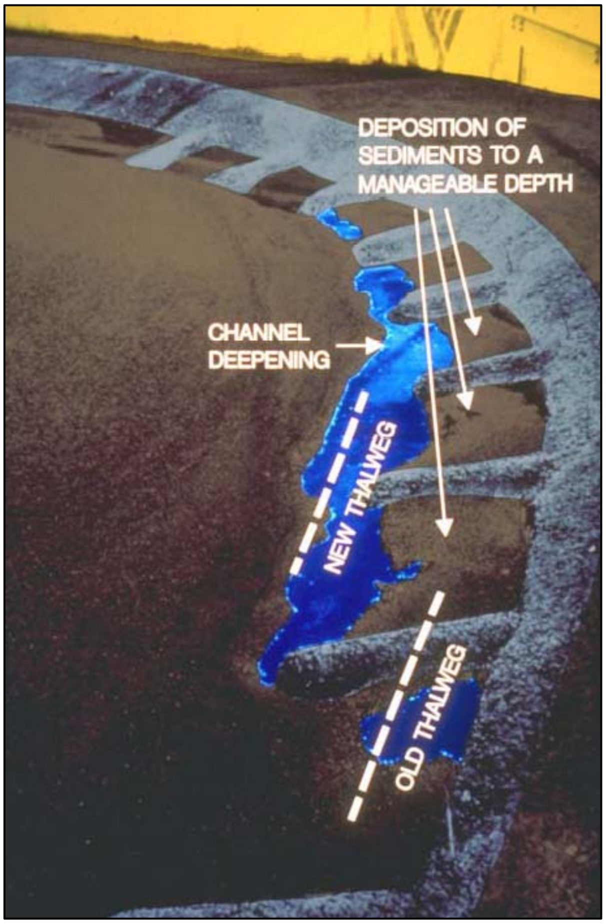


Figure 5.8. Bendway Weirs: Functions

The Missouri Department of Conservation tested the diversity in habitats surrounding a test section of notched dikes. Their raw data showed a total of 4,512 fish and 45 different species. After studying the data, they found an increase in diversity and numbers of micro-invertebrates. To a lesser degree, fish communities were also found to have greater diversity. In addition, the larger problem of aquatic environment becoming terrestrial was resolved. The river channel is maintained, structures are basically self-maintained and biological diversity has increased. Figure 5.8 shows the functions of a bendway weir; figure 5.9 shows different types of weirs.

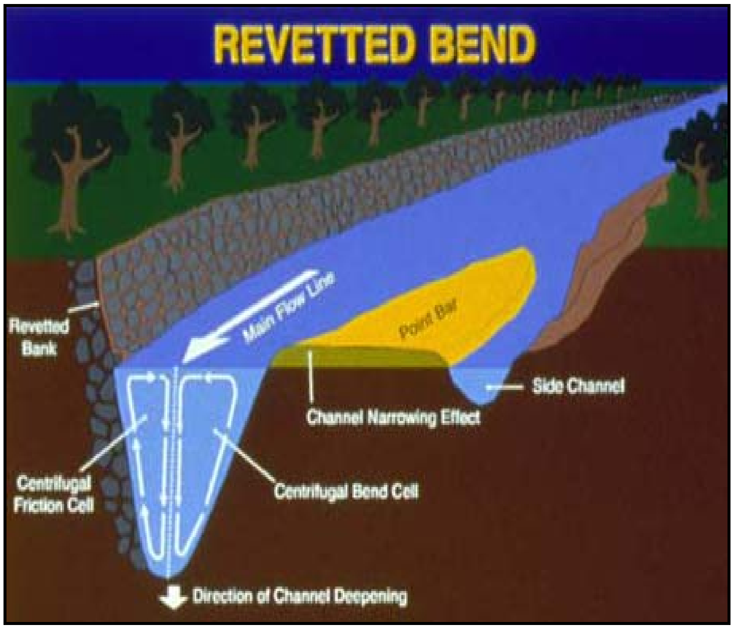
5.10.2. Lessons Learned. When placing weirs, construct downstream to upstream and it is critical to place the structures at an upstream angle of 30°. The design must consider the angle at which flow enters the bend; particularly in tight bends make sure the angle of attack is not through the weir field.

5.10.3. References

US Army Corps of Engineers, St. Louis District, *Environmental River Engineering on the Mississippi*, http://www.mvs.usace.army.mil/engr/river/Bendway/bw00.htm

Davinroy, R.D., *Bendway Weir Design Manual,* US Army Corps of Engineers, St. Louis District (1990).

5.10.4 Case Studies. Nearly 200 weirs have been placed in the Mississippi River since 1990.



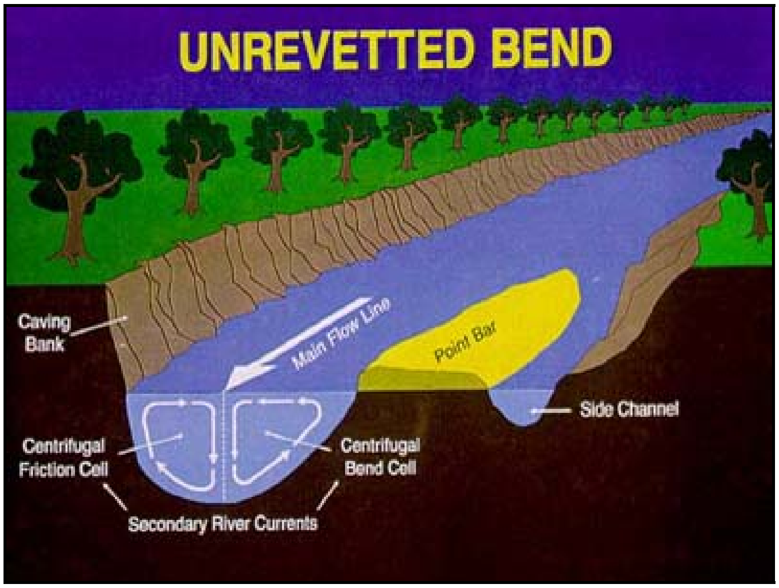


Figure 5.9. Bendway Weirs: Revetted and Unrevetted Bends

5.11. Blunt Nosed Chevrons

5.11.1. Design Methodology. Provide nose protection for islands while providing slower moving waters for fish habitat. Large rock used to provide structural stability and openings for habitat benefits. A navigation structure called a chevron dike was developed to improve river habitat and to create beneficial uses of dredged material. These structures are placed in the shallow side of the river channel pointing upstream. Their effect is to improve the river channel. When dredging is needed to improve the main navigation channel, dredged sediment is deposited behind the chevron dike. These small islands encourage the development of all four primary river ecosystem habitats. In addition, various microorganisms cling to the underwater rock structures, providing a food source for fish. Tests by the Illinois Department of Natural Resources studying habitat diversity surrounding bankline and off bankline revetments showed the use of larger rock provided habitat for a greater number of fish than either small stone revetment or the natural river bank. Figure 5.10 shows a blunt nosed chevron.

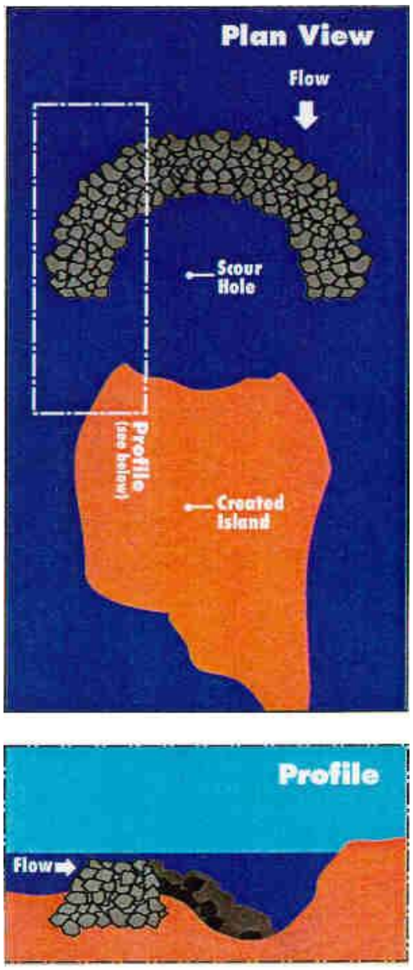


Figure 5.10. Blunt Nosed Chevron

5.11.2. Lessons Learned. The first three experimental chevrons were constructed in Pool 24 near UMRM 290 in 1993 solely for the purpose of protecting dredged material. Initial monitoring of the chevrons showed that they had immense environmental benefits by creating an abundance and variety of aquatic habitat. Since then, these chevrons as well as three additional chevrons near UMRM 266 have been extensively monitored. Fifty-one fish species and a highly diverse group of macro invertebrates have been collected in and around the structures. The 8 years of data also show a high presence of young of the year and juvenile fishes inside of the structures, which suggests that the structures are being used as nursery habitat. The data also shows that the outside edges of the chevrons are providing excellent habitat for quality-sized catfish. Catch rates inside the chevron have been more than double the catch rates outside of the structures. Vegetation colonization, very favorable water quality conditions, and wading bird use of the islands has also been documented.

The physical data collected in and around the structures show extensive depth, velocity, and substrate diversity which usually translates into habitat diversity. The structures create several different types of river habitat, with variable depth and flow velocities, and with multiple wetted edges or wetted perimeters where plant life can flourish. The diagram shows that flows, which overtop the structures, create a large scour hole inside of the chevron just downstream of the structure's apex. Downstream of this area, the reshaped material deposits and creates a shallow bar. After the flows drop below the crest of the structure, the scour hole formed at high flow becomes an area of deep slack water. This environment is very conducive to the needs of overwintering fish and provides the ideal conditions for a nursery for juvenile and larval fish. The plant life that establishes along the wetted edges provides good cover and habitat for young fish.

5.11.3. References

http://www.mvs.usace.army.mil/engr/ed/River/EnvironEng/EnvironRiverEngDoc.pdf, p 22.

US Army Corps of Engineers, St. Louis District, *Environmental River Engineering on the Mississippi*, http://www.mvs.usace.army.mil/engr/river/EnvironEng/en01.htm

Rock Island District Internet, EMP Habitat Rehabilitation and Enhancement Projects http://www.mvr.usace.army.mil/EMP/hrep.htm

Davinroy, R., Redington, S., Strauser, C., 1996: *Design of Blunt Nosed Chevrons in the Mississippi River for Sediment Management*, Proceedings of the 6th Federal Interagency Sedimentation Conference.

Gordon, D., Davinroy, R., Riiff, E., 2001*: Sedimentation Study of the Upper Mississippi River at Bolters Bar / Iowa Island, River Miles 230 to 223; Hydraulic Micro Model Investigation,* U.S. Army Corps of Engineers, St. Louis District.

Gordon, D., *Chronic Dredging on the Upper Mississippi River Remedied with Innovative River Training Structures,* On Course PIANC Magazine AIPCN, April 2005.

http://www.mvs.usace.army.mil/engr/ed/River/MicroModel/MainFrame.htm

5.11.4. Case Studies. La Grange Island. The Chevron is designed to protect the nose of the island and the sharply vertical bankline. Original rock armor has eroded exposing soft nose which is eroding. Chevron ends tied in to armor bankline due to excessive cost for flattening slope. Backwater channel side left open to provide slow waters providing fish habitat. The design was originally to fill area in with dredged material, but that feature was dropped. Large, (600-1200 lb) rock was desired, but logistical difficulties necessitated smaller, 400 lb rip-rap to be used. Chevrons upstream of Cottonwood Island are shown in photograph 5.7

Photograph 5.7. Cottonwood Island Chevrons

5.12. Off-Bankline Revetment

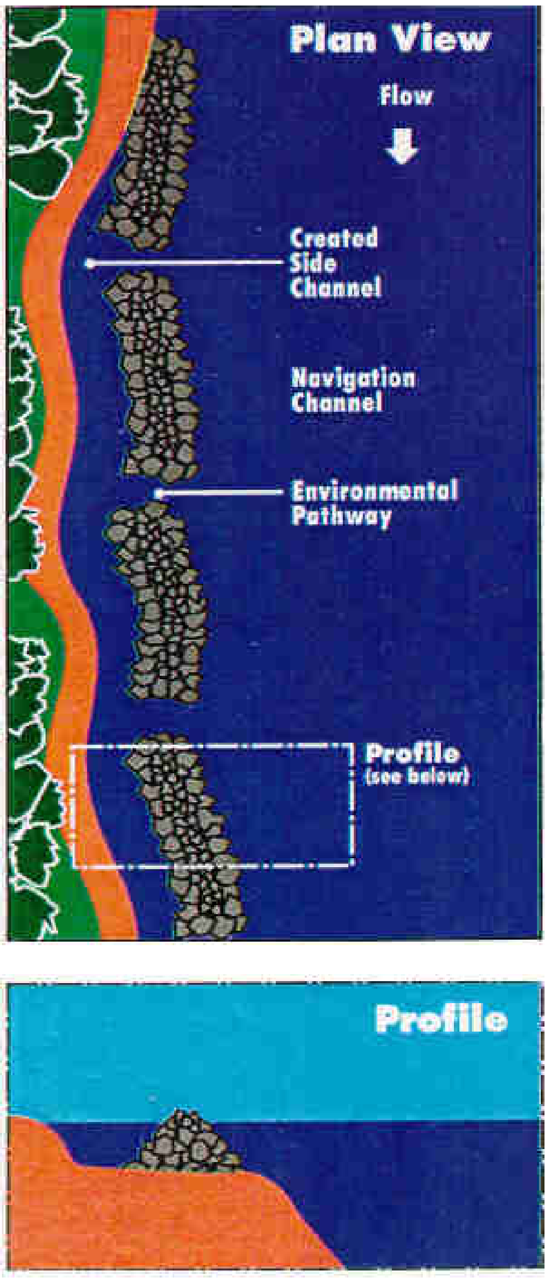


Figure 5.11. Off-Bankline Revetment

5.12.1. Design Methodology

In areas where the caving river bank is on the shallow side of the river, there is a greater flexibility to design alternative solutions.

By placing a parallel structure of stone off the bankline, erosion is reduced and diverse habitats are maintained. In some areas, the revetment is notched allowing fish to move between the fast water and the slow water easily. The areas between the revetments and the bank line are considered to be prime fishing locations by both commercial and recreational fishermen (figure 5.11).

5.12.2. Lessons Learned. None listed.

5.12.3. References

USACE, St. Louis District, *Environmental River Engineering on the Mississippi*, www.mvs.usace.army.mil/engr/river/EnvironEng/en01.htm

5.12.4. Case Studies. None listed.

5.13. Hard Points in Side Channels

5.13.1. Design Methodology. Hard points (figure 5.12) are a concentration of stone or other material placed at regular intervals along the eroding bank. Hard points can be trenched in, keyed in, or just dumped on the existing bank. The hard points work by resisting the acting forces associated with bank failure.

Figure 5.12. Hard Points

5.13.2. Lessons Learned. Success depends on the ability of the stone to launch into the scour hole formed from the hard point. Some bank scalloping can be expected between hard points. Little or no bank grading or reshaping is needed. Good choice for straight reaches and large radius bends; not recommended in areas suffering impinging flow, or for high degree-of-curvature, small radius bends. Hard points include several good environmental features including: semi-protected slack water areas between hard points; scour hole at stream end of hard point; vertical scalloped banks between hard points; and natural the vegetation on the banks and the crowns of hard points provides cover and a source of carbon loading to the system.

5.13.3. References

USACE, St. Louis District, *Environmental River Engineering on the Mississippi*

http://www.mvs.usace.army.mil/engr/river/EnvironEng/en18.htm

Derrick, David L. (2005); *#6 Re-directive-Compressed*

5.13.4. Case Studies. Hard points were constructed in the Duck Island side channel to protect the bankline of a large radius bend. Hard points were built in the Owl Creek reach not to protect the bankline but to create a scour pattern to separate a large sandbar from the bankline (photographs 5.8 and 5.9).

Photograph 5.8. Hard Points

Photograph 5.9. Hard Points

5.14. Vanes

Design Methodology

Rock vanes are in-stream structures constructed for the purpose of reducing shear stress on streambanks. Rock vanes shall consist of both Footer Rocks, placed below the invert of the proposed channel, as well as Vane Rocks.
Rock vanes should be constructed of angular, flat or cubed rock. When possible, consideration should be given to obtaining rock that is similar in color and texture to the native stone in the project area.

Rock be of sufficient hardness to resist weathering and shall be free of cracks and other blemishes. Porous rock such as some limestones and soft rock as shale are not allowed nor will concrete or other "debris" be allowed. Figure 5.13 shows typical vane details.

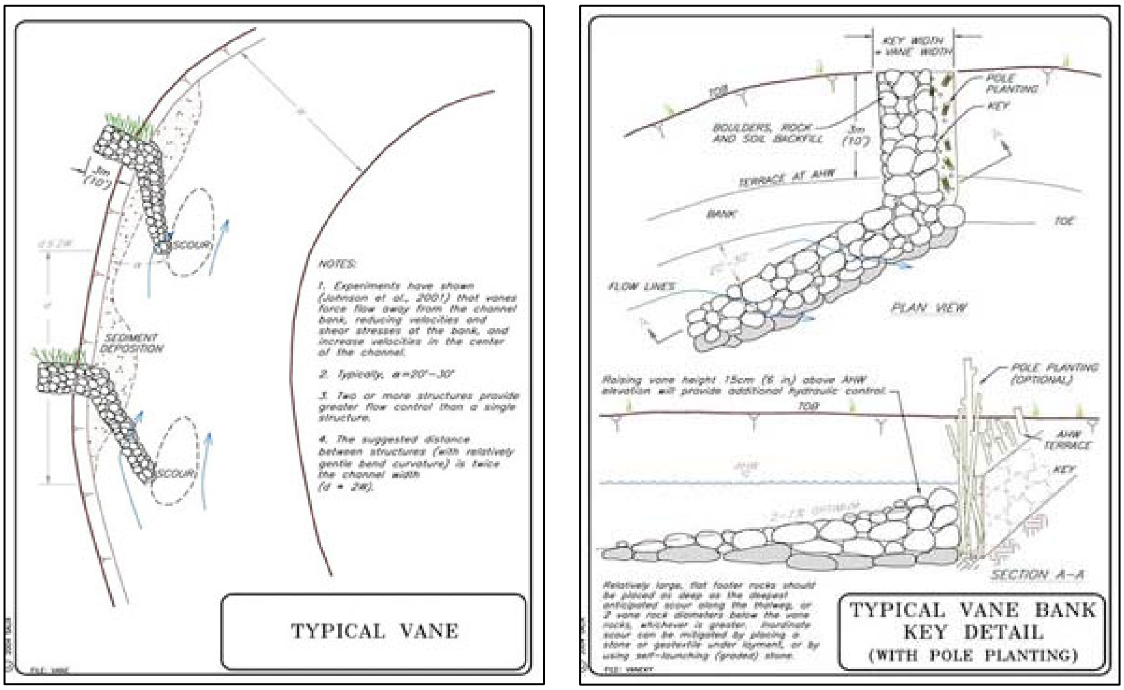


Figure 5.13. Typical Vane Details

Iowa Vanes are small, double-curved, patented structures for sediment management in rivers. They are designed to protect stream banks from erosion, maintain navigation depth and flood-flow capacity in rivers, and control sediment at diversions and water intakes. Figures 5.14 and 5.15 show flow around an Iowa vane.

The vanes are small, submerged flow-training structures or foils designed to modify the near-bed flow pattern and redistribute flow and sediment transport within the channel cross section. The vanes function by generating secondary circulation in the flow. The circulation alters magnitude and direction of the bed shear stresses and causes a change in the distribution of velocity, depth, and sediment transport in the area affected by the vanes. As a result, the riverbed aggrades in one portion of the channel cross section and degrades in another.

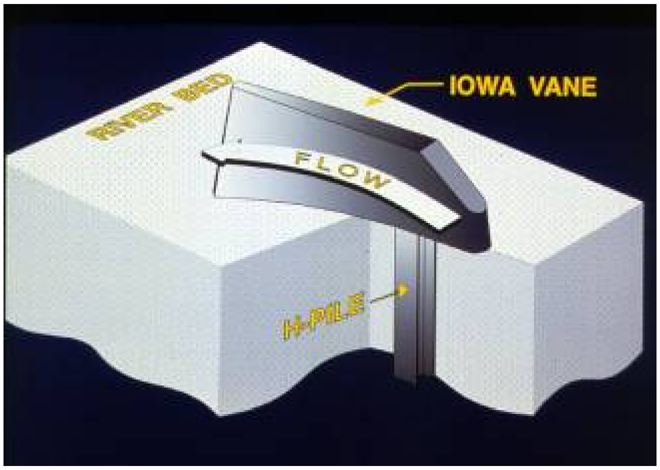


Figure 5.14. Iowa Vane

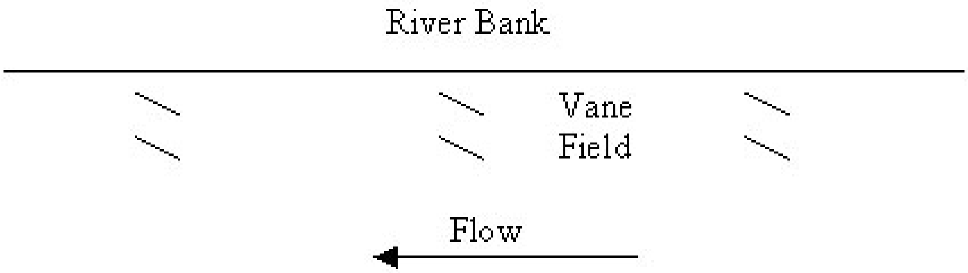


Figure 5.15. Flow Field

Russian engineers Potapov and Pyshkin (1947) originally proposed the use of vanes or panels for flow training. However, it is only recently that efforts have been made to optimize vane design and document performance. The first known attempts to develop a theoretical design basis were by Odgaard and Kennedy (1983) and Odgaard and Spoljaric (1986). Odgaard and Kennedy's efforts were aimed at designing a system of vanes to stop or reduce bank erosion in river curves. In such an application, the vanes are laid out so that the vane-generated secondary current eliminates the centrifugal induced secondary current, which is the root cause of bank undermining. The centrifugal induced secondary current in river bends results from the difference in centrifugal acceleration along a vertical line in the flow because of the non-uniform vertical profile of the velocity. The secondary current forces high-velocity surface current outward and low-velocity near-bed current inward. The increase in velocity at the outer bank increases the erosive attack on the bank, causing it to fail. By directing the near-bed current toward the outer bank, the submerged vanes counter the centrifugal induced secondary current and, thereby, inhibit bank erosion. The vanes stabilize the toe of the bank. The vanes can be laid out to make the water and sediment move through a river curve as if it were straight (table 5.8).

Table 5.8. Typical Vane Dimensions

Vane height, H	1-3 m (0.2-0.3 times design flow depth)
Vane thickness	0.05-0.20 m
Vane length, L	3H
Lateral spacing	3H
Longitudinal spacing	30H
Distance to bank or intake	3H
Angle of attack	20 degrees
Vane material	Wood, sheet pile, concrete

5.14.2. Lessons Learned. The upstream angle of the structure is critical. For the structure to work properly the upstream angle needs to be into the bank in the downstream direction. The resultant flow will be at a 90 ° angle perpendicular to the vane.

5.14.3. References

Derrick, David L. (2005); *#6 Re-directive-Compressed*

Odgaard, Jacob A., IIHR- Hydroscience & Engineering, College of Engineering, *The University of Iowa, Iowa Vanes – An Inexpensive Sediment Management Strategy* http://www.iihr.uiowa.edu/projects/IowaVanes/

Rosgen, Dave (1996): *Applied River Morphology*

5.14.4. Case Studies

Little Topashaw Creek, Durham-Calhoun City area, MS

Little Blue River, Marysville, KS

West Fork Cedar River, IA. Photograph 5.10 shows the vane-induced shift of the main channel. The installation consists of 12 vanes installed along the right-bank upstream of the bridge. Each vane consists of vertical sheet piles driven into the streambed and aligned at 20 degrees with the 1984 mean flow direction. Each sheet piling is 3.7 m long, and its top elevation is 0.6 m above the streambed.

Photograph 5.10. Aerial Photo of West Fork Cedar River (Iowa) Bridge Crossing (Left) Prior to Vane Installation in 1984, and (Right) in 1989, Five Years after Vane Installation

Kosi River, Nepal. Photograph 5.11 is of vanes being installed outside new water intake on Kosi River, Nepal. The vane system will prevent sediment from being entrained into the intake (left). Each vane is 6 m long and 1.5 m-tall (with 0.8 m of vane below average bed level). Longitudinal spacing varies between 30 m and 40 m; lateral spacing is 5 m.

Photograph 5.11. Vane System - Kosi River, Nepal.

5.15. Cross Vane and Double Cross Vane

5.15.1. Design Methodology. This structure was designed to off-set the adverse effects of straight weirs, and check dams, which create backwater and flat slopes. It was also designed to avoid the problems of the downstream pointing weirs which create twin parallel bars and a scour hole which de-stabilizes the structure. The objectives of this structure are to: (1) create instream cover/holding water; (2) take excess shear stress from the "near bank" region and direct it to the center of the stream to maintain later stability; (3) increase stream depth by decreasing width/depth ration; (4) increase sediment transport capacity; (5) provide a natural sorting of gravel (where naturally available) on the up-welling portion on the downstream side of the structure for spawning redds , and; (6) create grade control to prevent down cutting.

Rock be of sufficient hardness to resist weathering and shall be free of cracks and other blemishes. Porous rock such as some limestones and soft rock as shale should not be used. In some cases, native rock present on the site may be authorized for use by the Contracting officer. In no instance will concrete or other "debris" be allowed. All rock under this specification shall meet the conditions of material specification MS-01 Rock. Typical details are shown in figure 5.16.

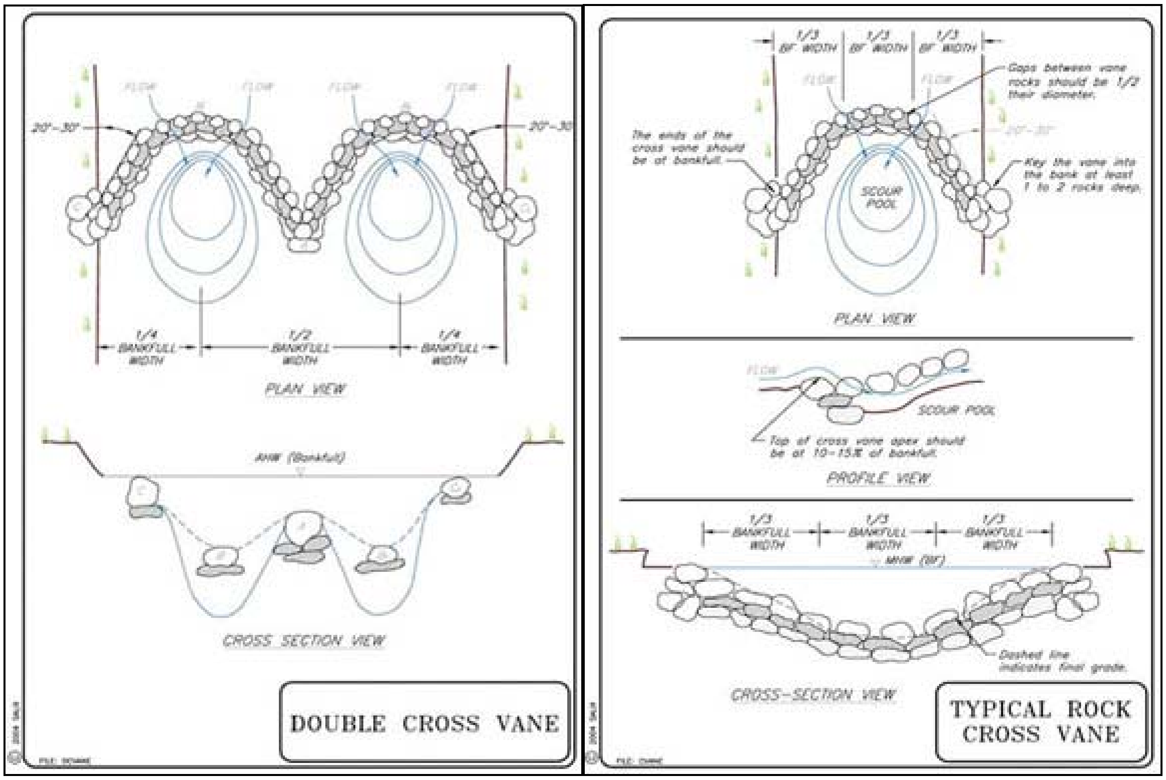


Figure 5.16. Typical Cross Vane Details

5.15.2. Lessons Learned. When the rock is placed, make sure that the footer rocks are working in compression with flow or the integrity of the structure will be compromised. When building the structure, alternate the size of the stone, allowing voids in the structure to allow for fish passage. If used as a grade control structure and the head cut is relatively high, use a series of structures instead of one large structure to allow for fish passage.

5.15.3. References

Derrick, David, L. (2005): *#6 Re-directive-Compressed*

McCullah, John (2004): *Environmentally-Sensitive Streambank Stabilization*

Rosgen, Dave (1996): *Applied River Morphology*

5.15.4. Case Studies. The Mason/Stalcup project, located along the upper portion of Little Brasstown Creek and Pinhook Branch in North Carolina.

5.16. J-Hook

5.16.1. Design Methodology. J-Hook Rock Vanes (figure 5.17) are structures designed to re-direct velocity distribution and high velocity gradient in the near-bank region, stabilize stream-banks, dissipate energy in deep, wide and long pools are created below the structure, and create holding cover for fish and spawning habitat in the tail-out of the structure. The basic function of the structure utilizes the principle that water will flow over immoveable objects at right angles (90° angles). The device is constructed of large stone that is tied into the streambank. The stone is trenched into two rows at an upstream angle of 20° to 30° at a distance of 1/3 stream width. The stone is then formed into a hook shape to cover a distance of 1/3 stream width. The downstream row of rock is trenched into the stream bottom so that the top of the rock is approximately level with the stream bottom.

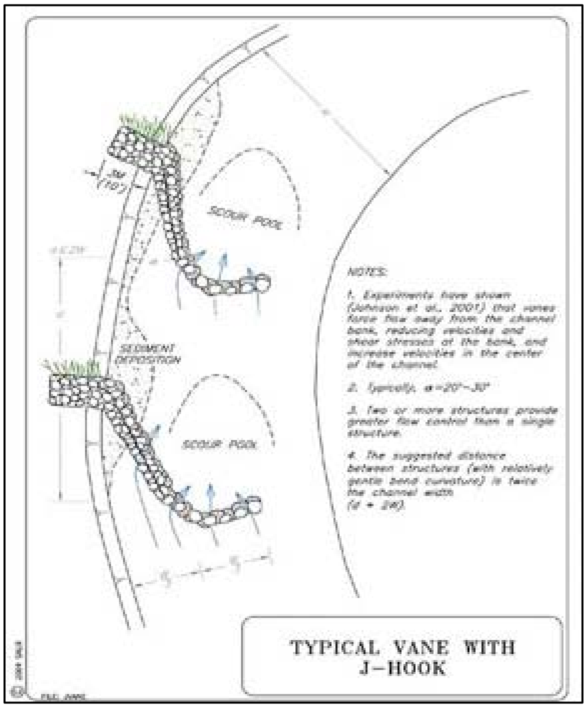


Figure 5.17. Vane with J-Hook

The second row of rock is then placed just upstream of that row of rock slightly overlapping it so that the water flows over the top of the upstream line of rock slightly overlapping it that as the water flows over the top of the upstream line of rock it will flow onto the downstream line of rock. This creates a stable surface on which the energy of the stream can be dissipated without completely scouring the stream bottom. As the stream dissipates its energy, it will scour the stream bottom slightly, creating a small scour pool immediately downstream of the device that serves as a source of aquatic habitat.

5.16.2. Lessons Learned. When the rock is placed, make sure that the footer rocks are working in compression with flow or the integrity of the structure will be compromised. When building the structure, alternate the size of the stone, allowing voids in the structure to allow for fish passage.

5.16.3. References

Derrick, David, L. (2005): *#6 Re-directive-Compressed*

McCullah, John (2004): *Environmentally-Sensitive Streambank Stabilization*

Rosgen, Dave (1996): *Applied River Morphology*

5.16.4. Case Studies. Marion Creek, AK used J-Hook Structure, shown in photograph 5.12

Photograph 5.12. Marion Creek, AK

5.17. Multiple Roundpoint Structures

5.17.1. Design Methodology. Multiple Roundpoint Structures (MRS) (figure 5.18) are used to create bathymetric and flow diversity in streams and rivers. Multiple Roundpoint Structures induce scouring off the tips of the tips of the structures and create depositional areas with the increased roughness generated by the structures. Flow diversity is created with high velocities off the tips of the structures and slack water areas down stream of the structures. The MRS can also act as a primitive bank stabilization technique by creating depositional zones near the banks of the structures.

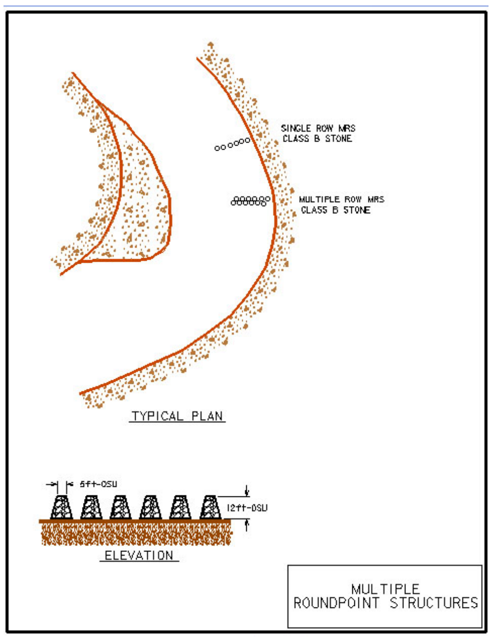


Figure 5.18. Multiple Roundpoint Structures

The structures are generally built to 2/3 bankfull and the grade of stone needed is channel dependent. The spacing of the MRS is dependent of the height of the structure and natural angle of repose the rock used. A rule of thumb with the spacing between the structures is space them no less than 2/3 of the height.

Multiple Roundpoint Structures can be designed as a single row or in multiple rows. Preliminary data shows that the more rows incorporated generate increased bathymetric changes.

5.17.2. Lessons Learned. Multiple Roundpoint Structures are not recommended as a bank stabilization technique but can be incorporated with other forms of bank stabilization such as revetment or LPSTP. The data collected suggest that MRS are providing useful and valuable habitat for a variety of riverine fishes. Collection of blue suckers may indicate these structures are providing a unique habitat type, once more common in the river.

5.17.3. References

US Army Corps of Engineers, St. Louis District, *Melvin Price Locks and Dam, Upper Mississippi River Missouri and Illinois, Progress Report 1999, Design Memorandum No. 24 Avoid and Minimize Measures,* May 2000.

5.17.4. Case Studies

US Army Corps of Engineers, St. Louis District Riprap Landing Multiple Roundpoint Structures, Middle Mississippi River Mile 265.7.

5.18. Environmental Dredging

5.18.1. Design Methodology. Side channels of rivers are important spawning and rearing habitat for fish. Their slower waters offer less scouring of eggs during flooding and offer better tree cover and logs in the water to hide fry after they emerge from the gravel. In a naturally functioning watershed, side channels may become isolated from the river and slowly fill in with sediment and vegetation. This eutrophication process happens much faster in shallow, narrow side channels than in deep wide lakes. Side channels can go from productive fish habitat to dry land in less than 50 years. Reopening theses side channels by the process of dredging is termed "environmental dredging". Dredging in the St. Louis district is accomplished by using hydraulic pipeline dredges. (photograph 5.13)

Photograph 5.13. Dredge

A hydraulic dredge mixes large quantities of water with the excavated material (almost always sand in the St. Louis District) to create a slurry which is then pumped out of the navigable channel. The two types of hydraulic pipeline dredges used by St. Louis are the *Dustpan* and the *Cutterhead.* The Dustpan Dredge was specifically designed by USACE for work on the Mississippi River. The Dustpan is very efficient in excavating sand material from the river bottom. Water jets at the end of the suction head agitate the sand into a slurry which is then pumped up into the dredge. The discharge is pipelined a short distance, typically around 800 feet, outside of the navigable channel. A

Cutterhead Dredge has an active rotating auger surrounding the suction line. The material is pumped up to the dredge and discharged through a pipeline up to 3000 feet away.

5.18.2. Lessons Learned. Dredging is coordinated with other Government Agencies so that our operations are conducted in an environmentally sensitive manner. It is a continual process and new techniques are continually being developed to reduce the environmental impact that is associated with channel dredging.

5.18.3. References

US Army Corps of Engineers, Rock Island District, *Garner Division, Habitat Rehabilitation and Enhancement Project, Pool 21, Upper Mississippi River Miles, 332.5 – 340.2*

5.18.4. Case Studies

US Army Corps of Engineers, Rock Island District Dredge 5,000 feet of O'Dell Chute, Pool 21, Upper Mississippi River Miles 332.5 – 340.2,

5.19. Longitudinal Peak Stone Toe Protection (LPSTP)

5.19.1. Design Methodology. A continuous stone dike comprised of well sorted, self launching stone, placed at, or slightly streamward of, the toe of the eroding bank. The cross-section is triangular. The LPSTP does not necessarily follow the toe exactly, but can be placed to form a "smoothed" alignment through the bend. The amount of stone used is based on tons per linear foot. In determining the tonnage you first must calculate the depth of scouring resulting in the stone placement. 2 tons/linear ft are the most common tonnage, resulting in approximately 5 feet of toe protection.

The design considerations for LPSTP keys are the following: they must be keyed into the bank at both the upstream and downstream ends and at regular intervals along the entire length. Typically the keys are spaced at 50 to 100ft intervals up to 1 to 2 channel widths on larger waterways. Keys at the upstream and the downstream ends of the LPSTP should not be at a 90 ° angle to the structure, but at 20 to 30° to flow. Keys should go far enough into the river bank so river migration will not flank the key and the LPSTP (figure 5.19 and photograph 5.14).

5.19.2. Lessons Learned. The success depends on the ability of the stone to launch into the scour hole. River bank grading is not necessary. The weight of stone (loading of toe) might resist some shallow-fault geotechnical bank failures. The LPSTP captures alluvium and upslope failed material on bank side of structure. Works well where outer bank alignment makes abrupt changes, where the bank must be built back into the stream (realignment of channel, or construction of a backfilled vegetative bench or terrace for habitat improvement and/or velocity attenuation), where a minimal continuous bank protection is needed, or where a "false bankline" is needed. Works well in combination with other methods (bendway weirs, spur dikes, bioengineering, joint planting, live siltation, and live staking).

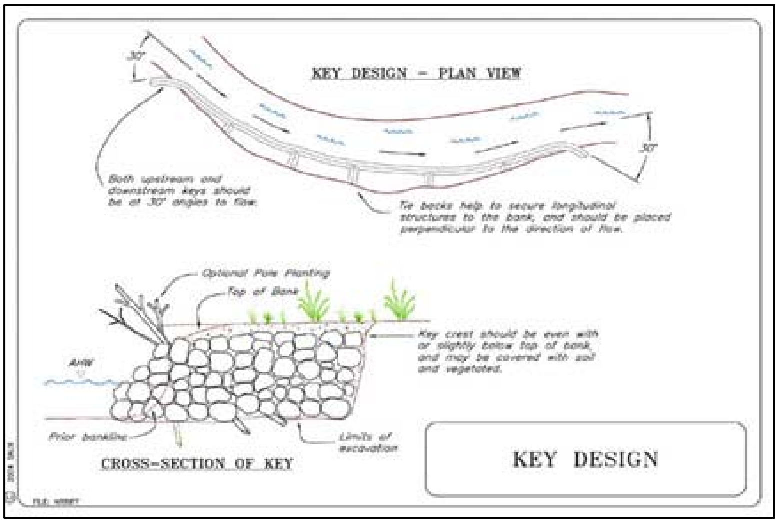
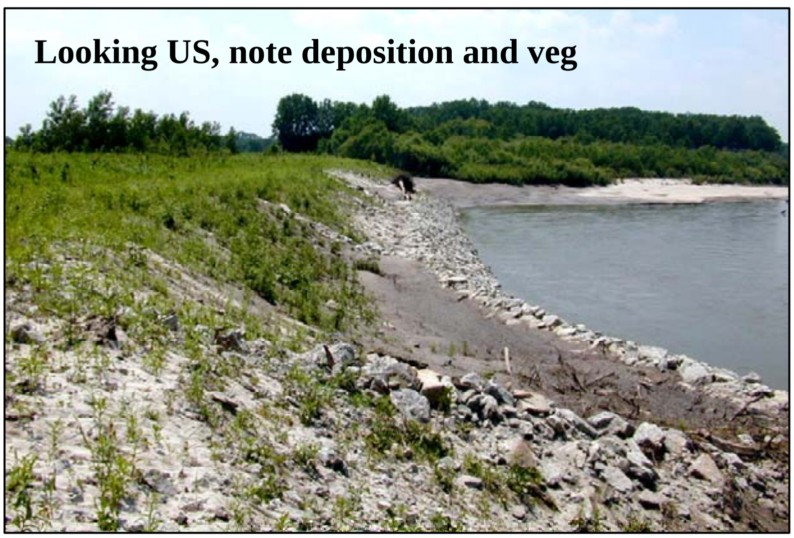


Figure 5.19. Longitudinal Peak Stone Toe Protection



Photograph 5.14 Longitudinal Peak Stone Toe Protection

5.19.3. References

Derrick, David, L. (2003): *Streambank Methods II Redirective Techniques; Stream Investigation, Stabilization and Restoration Session 4*

McCullah, John (2004): *Environmentally-Sensitive Streambank Stabilization*

5.19.4. Case Studies

Harland Creek Bendway Weir-Willow Post Demonstration Project
Las Vegas Wash, Las Vegas, NV

5.20. Bioengineering and Biotechnical Engineering

Vegetation has been used increasingly over the past few decades to control streambank erosion or as a bank stabilizer. It has been used primarily in stream restoration and rehabilitation projects and can be applied independently or in combination with structural countermeasures. There are several synonymous terms that describe the field of vegetative streambank stabilization and countermeasures. Terms for the use of 'soft' revetments (consisting solely of living plant materials or plant products) include bioengineering, soil bioengineering, ground bioengineering, and ecological bioengineering. Terms describing the techniques that combine the use of vegetation with structural (hard) elements include biotechnical engineering, biotechnical slope protection, bioengineered slope stabilization, and biotechnical revetment. The terms soil bioengineering and biotechnical engineering are most commonly used to describe stream bank erosion countermeasures and bank stabilization methods that incorporate vegetation.

The effective application of soil bioengineering and biotechnical engineering techniques requires expertise in channel and watershed processes, biology, and streambank stabilization techniques. Due to a lack of technical training and experience, there is a reluctance to resort to soil bioengineering and biotechnical engineering techniques and stability methods. In addition, bank stabilization systems using vegetation have not been standardized for general application under particular flow conditions.

There is a lack of knowledge about the properties of the materials being used in relation to force and stress generated by flowing water and there are difficulties in obtaining consistent performance from countermeasures that rely on living materials. Photograph 5.15 shows an example of bioengineering.

Photograph 5.15. Rock Vanes with Bioengineering, Urban Setting, Charlotte, NC

5.20.2. Advantages and Disadvantages of Biotechnical Engineering. Specific ways vegetation can protect stream banks as part of a biotechnical engineering approach include:

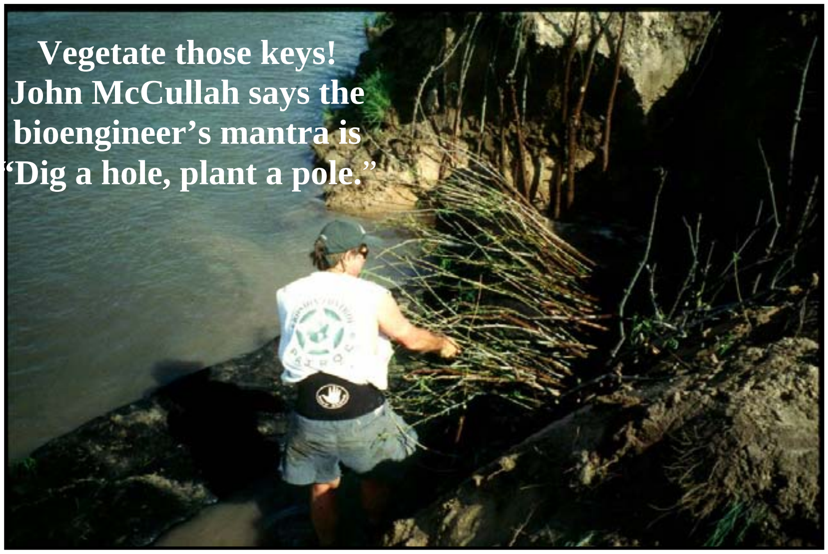
- The root system binds soil particles together and increases the overall stability and shear strength of the bank.
- The exposed vegetation increases surface roughness and reduces local flow velocities close to the bank, which reduces the transport capacity and shear stress near the bank, thereby inducing sediment deposition.
- Vegetation dissipates the kinetic energy of falling raindrops, and depletes soil water by uptake and transpiration.
- Vegetation reduces surface runoff through increased retention of water on the surface and increases groundwater recharge.
- Vegetation deflects high-velocity flow away from the bank and acts as a buffer against the abrasive effect of transported material.
- Vegetation improves the conditions for fisheries and wildlife and helps improve water quality.

In addition, biotechnical engineering is often less expensive than most methods that are entirely structural and it is often less expensive to construct and maintain when considered over the long-term.

5.20.2. Design Methodology . The critical threats to the successful performance of biotechnical engineering projects are improper site assessment, design or installation, and lack of monitoring and maintenance (especially following floods and during droughts). Some of the specific limitations to the use of vegetation for streambank erosion control include:

- Lack of design criteria and knowledge about properties of vegetative materials
- Lack of long-term quantitative monitoring and performance assessment
- Difficulty in obtaining consistent performance from countermeasures relying on live materials
- Possible failure to grow and susceptibility to drought conditions
- Depredation by wildlife or livestock
- It may require significant maintenance

More importantly, the type of plants that can survive at various submersions during the normal cycle of low, medium, and high stream flows is critical to the design, implementation, and success of biotechnical engineering techniques. A bioengineering technique is shown in photograph 5.16.



Photograph 5.16. Bioengineering

5.20.3. Design Considerations for Biotechnical Engineering. In an unstable watershed, careful study should be made of the causes of instability before biotechnical engineering is contemplated (see FHA HEC-20,(23) Chapter 4, Reconnaissance Classification, and Response). Since bank erosion is tied to channel stability, a stable channel bed must be achieved before the banks are addressed. Scour and erosion of the bank toe produce the dominant failure modes (see FHA HEC-20(23)), consequently, most biotechnical engineering projects documented in the literature contain some form of structural (hard) toe stabilization, such as rock riprap (figure 5.20), rock gabions, cribs, cable anchored logs, or logs with root wads anchored by boulders (figure 5.21). Toe protection should be keyed into the channel bed sufficiently deep to withstand significant scour and the biotechnically engineered revetment should be keyed into the bank at both the upstream and downstream ends (called refusals) to prevent flanking. Deflectors such as fences, dikes, and pilings may also be utilized to deflect flow away from the bankline.

Other factors that need to be considered when selecting a design option include climate and hydrology, soils, cross-sectional dimensions (is there sufficient room for the countermeasure), flow depth, flow velocity (both magnitude and direction), and slope of the bankline being protected. Most methods of biotechnical engineering will require some amount of bank regrading. Because structure design is based on flood velocities and depths, one or more design flows will need to be analyzed. Of particular interest is the bankfull or overtopping event, since this event generates the greatest velocities and tractive forces. Local (at or near the project site) flow velocities should be used for the design, especially along the outside of bends. The erosion protection should extend far enough downstream, particularly on the outer banks of bends. The highest velocities generally occur at the downstream arc of a bend and on the outer bank of the exit reach immediately downstream. As noted, the countermeasures should be tied into the bank at both ends to prevent flanking.

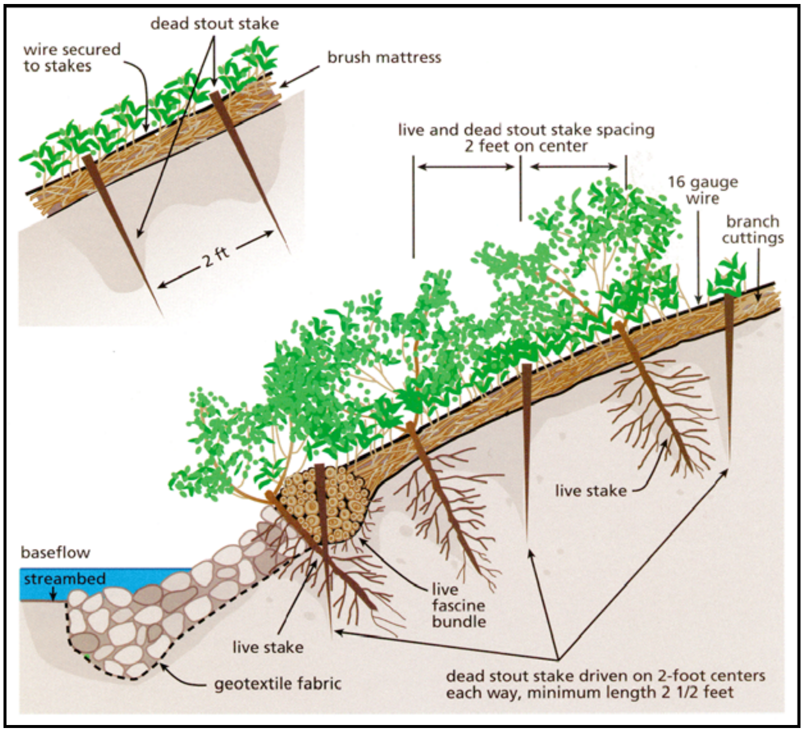


Figure 5.20. Details of Brush Mattress Technique With Stone Toe Protection

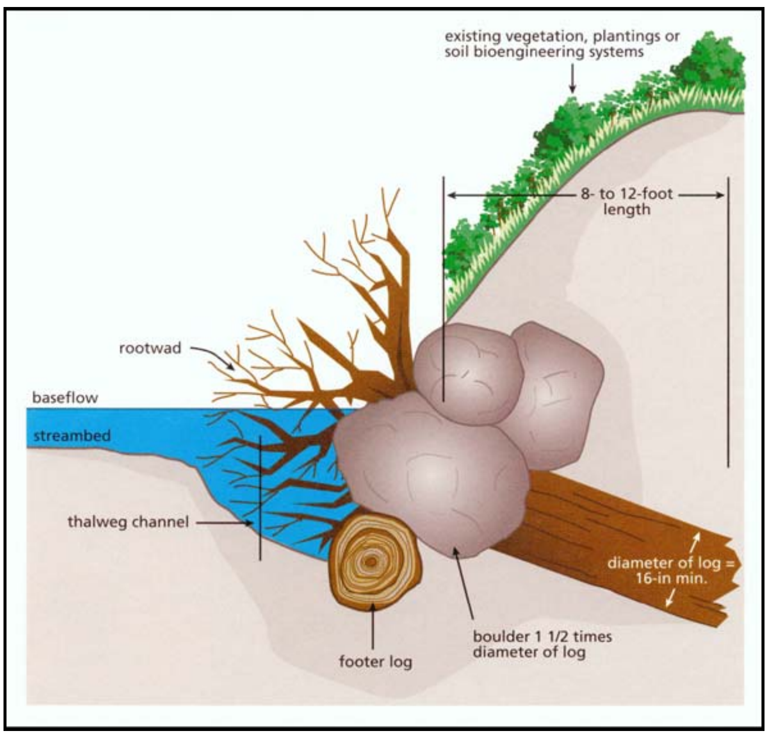


Figure 5.21. Details of Rootwad and Boulder Revetment Technique

5.20.4. Streambank Zones. As indicated by U.S. Army Engineer Waterways Experiment Station (WES), (50) plants should be positioned in various elevational zones of the bank based on their ability to tolerate certain frequencies and durations of flooding, and their attributes of dissipating current- and wave energies. The stream bank is generally broken into three or four zones to facilitate prescription of the biotechnical erosion control treatment. Because of daily and seasonal variations in flow, the zones are not precise and distinct. The zones are based on their bank position and are defined as the toe, splash, bank and overbank zones (figure 5.22.)

The toe zone is the area between the bed and the average normal stage. This zone is often under water more than six months of the year. It is a zone of high stress and is susceptible to undercutting and scour resulting in bank failure.

The splash zone is located between the normal high-water and normal low-water stages and is inundated throughout much of the year (at least six months). Water depths fluctuate daily, seasonally, and by location within the zone. This zone is also an area of high stress, being exposed frequently to wave-wash, erosive currents, ice and debris movement, wet-dry cycles, and freeze-thaw cycles.

Because the toe and splash zones are the zones of highest stress, these zones are treated as one zone with a structural revetment, such as rock, stone, logs, cribs, gabions, or some other 'hard' treatment. Within the splash zone, flood-resistant herbaceous emergent aquatic plants like reeds, rushes, and sedges may be planted in the structural element of the bank protection.

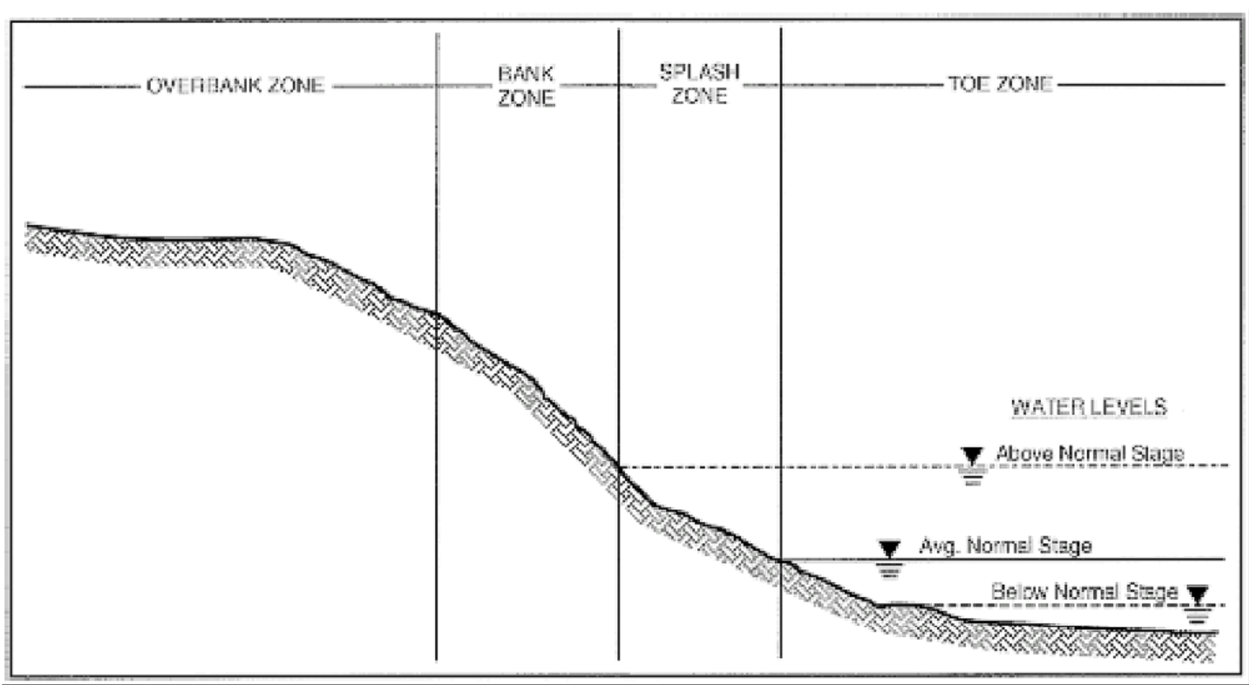


Figure 5.22. Bank Zones Defined for Slope Protection

The bank zone is usually located above the normal high-water level, but is exposed periodically to wave-wash, erosive flows, ice and debris movement, and traffic by animals or man. This zone is inundated for at least a 60-day duration once every two to three years and is influenced by a shallow water table. Herbaceous (i.e., grasses, clovers, some sedges, and other herbs) and woody plants (i.e., willows, alder, and dogwood) that are flood tolerant and able to withstand partial to complete submergence for up to several weeks are used in this zone. Whitlow and Harris(54) provide a listing of very flood-tolerant woody species and a few herbaceous species by geographic area within the United States.

The overbank zone includes the top bank area and the area inland from the bank zone, and is usually not subjected to erosive forces except during occasional flooding. Vegetation in this zone is extremely important for intercepting overbank floodwater, binding the soil in the upper bank together through its root system, helping reduce super-saturation of the bank, and decreasing the weight of unstable banks through evapotranspiration processes. This zone can contain grasses, herbs, shrubs, and trees that are less flood-tolerant than those in the bank zone. The rooting depth of trees can be an extremely important part of bank stability. Besides erosion control, wildlife habitat diversity, aesthetics, and access for project construction and long-term maintenance are important considerations in this zone.

5.20.5. Biotechnical Engineering Treatments. Descriptions and guidelines for biotechnical engineering treatments or combinations of treatments, and plant species that can be used in the treatments are described in detail by WES,(50) Bentrup and Hoag,(48) and Schiechtl and Stern. The following is a brief summary of some of the major types of biotechnical engineering treatments that can be used separately or in some combination.

Toe Zone. Structural revetments such as riprap, gabions, cribs, logs, or rootwads in a biotechnical engineering application are used at the toe in the zone below normal water levels and up to where normal water levels occur. There are no definitive guidelines for how far up the bank to extend the structural revetment. Instead, it is common practice to extend the revetment from below the predicted contraction and local scour depth up to at least where the water flows the majority of the year. Vegetative treatments are placed above or behind this structural toe protection.

Splash Zone. Several treatments may be used individually or in combination with other treatments in the splash zone above or behind the structural toe protection. These include coir rolls and mats, brush mattresses, wattles or fascines, brush layering, vegetative geogrid, dormant posts, dormant cuttings, and root pads.

Coir is a biodegradable geotextile fabric made of woven fibers of coconut husks and is formed into either rolls (coir roll) or mats (coir fiber mats). Coir rolls are often placed above the structural toe protection parallel to the bank with wetland vegetation planted or grown in the roll. Coir fiber mats are made in various thicknesses and are often pre-vegetated at a nursery with emergent aquatic plants or sometimes sprigged on-site with emergent aquatic plants harvested from local sources.

Brush mattresses, sometimes called brush matting or brush barriers, are a combination of a thick layer of long, interlaced live willow switches or branches and wattling. Wattling, also known as fascine, is a cigar-shaped bundle of live, shrubby material made from species that root rapidly from the stem. The branches in the mattress are placed perpendicular to the bank with their basal ends inserted into a trench at the bottom of the slope in the splash zone, just above the structural toe protection. The fascines are laid over the basal ends of the brush mattress in the ditch and staked. The mattress and fascines are kept in place by either woven wire or tie wire that is held in place by wedge-shaped construction stakes. Both are covered with soil and tamped.

Brush layering, also called branch layering or branch packing, is used in the splash zone as well as in the bank zone. This treatment consists of live branches or brush that quickly sprout, such as willow or dogwood species, placed in trenches dug into the slope, on contour, with their basal ends pointed inward and the tips extending beyond the fill face. Branches should be arranged in a criss-cross fashion and covered with firmly compacted soil. This treatment can also be used in combination with live fascines and live pegs.

Vegetative geogrid is also used in the splash zone and can extend farther up into the bank zone and possibly the overbank zone. This system is also referred to as "fabric encapsulated soil" and consists of successive walls of several lifts of fabric reinforcement with intervening long, live willow whips. The fabric consists of two layers of coir fabric which provide both structural strength and resistance to piping of fine sediments.

Dormant post treatment consists of placing dormant, but living stems of woody species that sprout stems and roots from the stem, such as willow or cottonwood, in the splash zone and the lower part of the bank zone. Post holes are formed in the bank so that the end of the post is below the maximum predicted scour depth. Posts can also be planted in riprap revetments.

Streamco willows can be harvested at project construction inception so that material can be soaked for as long as possible to increase chances of survival during summertime planting Research shows that willow protected from the sun and soaked for 10 days will have twice as many plants survive, 100% initial flush, and 32 fold {2600%} more root biomass.

Dormant cuttings, also known as live stakes, consists of inserting and tamping live, single stem, rootable cuttings into the ground or sometimes geotextile substrates. In the splash zone of high velocity streams, this method is used in combination with other treatments, such as brush mattresses and root wads. Dormant cuttings can be used as live stakes in the brush mattress and fascines in the place of or in combination with the wedge-shaped construction stakes (figure 5.20).

Root pads are clumps of shrubbery composed of woody species that are often placed in the splash zone between root wads (figure 5.22). Root pads can also be used in the bank and overbank zones, but should be secured with stakes on slopes greater than 1V:6H.

Bank Zone. This zone can be stabilized with the treatments previously described as well as with sod, mulching, or a combination of treatments. Sodding of flood-tolerant grasses can be used to provide rapid bank stabilization where only mild currents and wave action are expected. The sod usually must be held in place with some sort of wire mesh, geotextile mesh such as a coir fabric, or stakes. Coir mats may extend into this zone. Shrub-like woody transplants or rooted cuttings are also effective in this zone and are often placed in combination with tied-down and staked mulch that is used to temporarily reduce surface erosion. For areas where severe erosion or high currents are expected, methods such as brush mattress should be carried into the bank zone.

Contour wattling consists of fascines, often used independent of the brush mattress, placed along contours, and buried across the slope, parallel or nearly parallel to the stream course. The bundles can be living or constructed from wood and are staked to the bank. Contour wattles are often installed in combination with a coir fiber blanket. Overseeding and straw mulch will help prevent the development of rills or gullies.

Brush layering with some modifications can be used in the bank zone. Geotextile fabrics should be used between the brush layers and keyed into each branch layer trench to prevent unraveling of the bank between the layers.

Overbank Zone. Bioengineered treatments are generally not used in this zone except to control gullying or where slopes are greater than 1V:3H. In these cases, brush layering or contour wattling may be employed across the gully or on the contour of the slope.

Deep-rooting plants, such as larger flood-tolerant trees, are required in this zone in order to hold the bank together. Care should be taken in the placement of trees that may grow to be fairly large since their shade can kill out vegetation in the splash and bank zones. Trees planted in the overbank zone are planted either as container-grown or bare-root plants.

Depending on their shade tolerance, grasses, herbs, and shrubs can be planted between the trees. Hydroseeding and hydromulching are useful and effective means of direct seeding in the overbank zone.

5.20.6. Summary . Biotechnical engineering can be a useful and cost-effective tool in controlling bank erosion or providing bank stability at highway bridges, while increasing the aesthetics and habitat diversity of the site. However, where failure of the countermeasure could lead to failure of the bridge or highway structure, the only acceptable solution may be traditional, "hard" engineering approaches. Biotechnical engineering needs to be applied in a prudent manner, in conjunction with channel planform and bed stability-analysis, and rigorous engineering design. Designs must account for a multitude of factors associated with the geotechnical characteristics of the site, the local and watershed geomorphology, local soils, plant biology, hydrology, and site hydraulics. Finally, programs for monitoring and maintenance, which are essential to the success and effectiveness of any biotechnical engineering project, must be included in the project and strictly adhered to.

5.20.7. Lessons Learned. Stabilization of eroding stream banks using vegetative countermeasures has proven effective in many documented cases in Europe and the United States. Most hydraulic engineers in Europe would not recommend the reliance on bioengineering countermeasures as the only countermeasure technique when there is a risk of damage to property or a structure, or where there is potential for loss of life if the countermeasure fails. Soil bioengineering is not suitable where flow velocities exceed the strength of the bank material or where pore water pressure causes failures in the lower bank. In contrast, biotechnical engineering is particularly suitable where some sort of engineered structural solution is required, but the risk associated with using just vegetation is considered too high. Nonetheless, this group of countermeasures is not as well accepted as the classical engineering approaches to bridge stability.

5.20.8. References

Derrick, David, L. (2003)*: Streambank Methods II Redirective Techniques; Stream Investigation, Stabilization and Restoration Session 4*

McCullah, John (2004): *Environmentally-Sensitive Streambank Stabilization*, www.biodraw.com

U.S. Department of Transportation, Federal Highway Administration, *Bridge Scour And Stream Instability Countermeasures, Experience, Selection, and Design Guidance,* Second Edition, Publication No. FHWA NHI 01-003, March 2001, Hydraulic Engineering Circular No. 23, chapter 4, pages 4.23-4.30.

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Escarameia, M., 1998, *River and Channel Revetments - A Design Manual,* Environment Agency R&D Publication 16, Thomas Telford, London.

Bentrup, G. and J.C. Hoag, 1998, *The Practical Streambank Bioengineering Guide: User's Guide for Natural Streambank Stabilization Techniques in the Arid and Semi-Arid Great Basin and Intermountain West,* Interagency Riparian/Wetland Plant Development Project, USDA Natural Resources Conservation Service.

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U.S. Army Engineers Waterways Experiment Station (WES), 1998, *Streambank Stabilization Handbook*, Veri-Tech, Inc., Vicksburg, MS.

The Federal Interagency Stream Restoration Working Group (FISRWG), 1998, *Stream Corridor Restoration: Principles, Processes, and Practices,* U.S. Dept. of Commerce, National Technical Information Service, Washington, D.C.

Schiechtl, H.M. and R. Stern, 1997, *Water Bioengineering Techniques for Water Course, Bank and Shoreline Protection* Blackwell Science, Inc., Cambridge, MA.

Morgan, R.P.C., A.J. Collins, M.J. Hann, J. Morris, J.A.L. Dunderdale, and D.J.G. Gowing, 1997, *Waterway Bank Protection: A Guide to Erosion Assessment and Management* Environment Agency, R&D Draft Technical Report W5/i635/3.

Whitlow, T.H. and R.W. Harris, 1979, *Flood Tolerance in Plants: A State-of-the-Art Review,* Technical Report E-79-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

5.20.9. Case Studies

Irwin Creek Greenway , Charlotte, NC,
http://www.charmeck.org/Departments/Park+and+Rec/Greenways/Irwin+Creek.htm

5.21. Wood Pile Structures

5.21.1. Design Methodology. Prior to the 1960s almost all of the structures placed in the Middle Mississippi River were of the woody pile type. Logs were basically driven in to the river bed to create roughness and formed into a river training structure. Similar to the currently see out on the systems today. Due to the need for continual maintenance of these woody structures river training structures began to be constructed from stone during the 1960s. There is currently a big push to start bringing back the woody pile structures because of there benefit to the micro and macroinvertebrate species.

5.21.2. Lessons Learned. Woody pile structures should only be used in areas where bathymetric diversity is your goal. The structures should not be used where maintaining a navigation channel is your priority.

5.21.3. References. Hundreds of structures placed throughout the Mississippi River prior to the 1960s

5.21.4. Case Studies. Apalachicola River, FL (photograph 5.17)

Photograph 5.17. Permeable Wooden Pile Dikes on the Apalachicola River, FL

5.22. Rootwad Revetment

5.22.1. Design Methodology. The objectives of this design are to: (1) protect the streambank from erosion; (2) provide in-stream and overhead cover for fish; (3) provide shade, detritus, terrestrial insect habitat; (4) look natural, and; (5) provide diversity of habitats (figure 5.23).

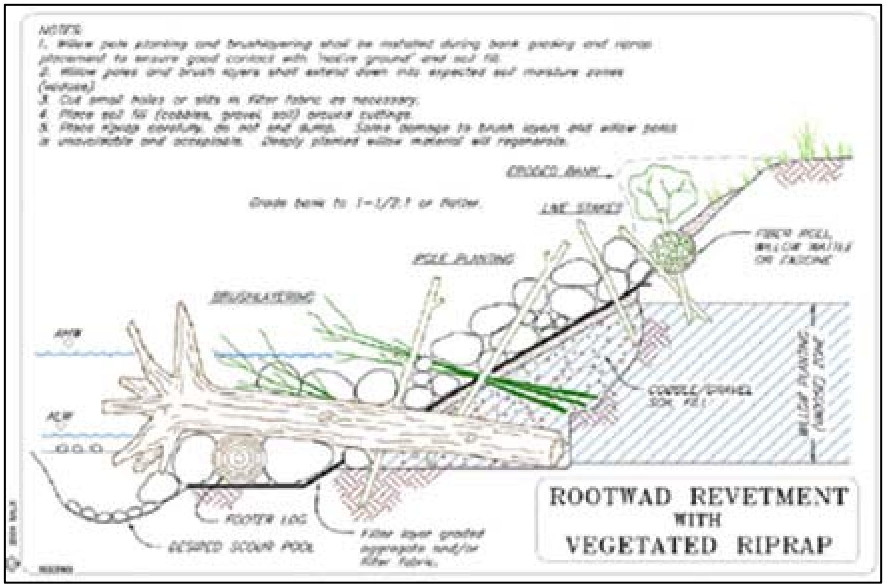

Figure 5.23. Rootwad Revetment

5.22.2. Lessons Learned. The position relative to the water surface, frequent wetting and drying reduces life; continuously submerged wood lasts the longest.

5.22.3. References

McCullah, John (2004): *Environmentally-Sensitive Streambank Stabilization*

Rosgen, Dave (1996): *Applied River Morphology*

5.22.4. Case Studies

Ministry of Transportation and Highways, Edgewood, British Columbia, *Bridge Approach Stabilization Using Vegetated Crib Wall Techniques, Inonoaklin River Project* (photograph 5.18).

Photograph 5.18. Bankline Stabilization

5.23. Woody Debris

5.23.1. Design Methodology. Naturally occurring large woody debris (LWD) (i.e., >10 cm diameter and 2 m in length) is an important component of many lotic systems. It provides roughness, reducing velocities and overhead cover for fishes, substrate for aquatic invertebrates, and can be an important source of particulate organic matter adding to primary productivity of a river.

Large woody debris dissipates flow energy, resulting in channel stability and improved fish migration. It also provides basking and perching sites for reptiles and birds. Positive effects of LWD are well-documented in high gradient streams, and recent studies show that the LWD is an important habitat component of low gradient streams with fine substrates.

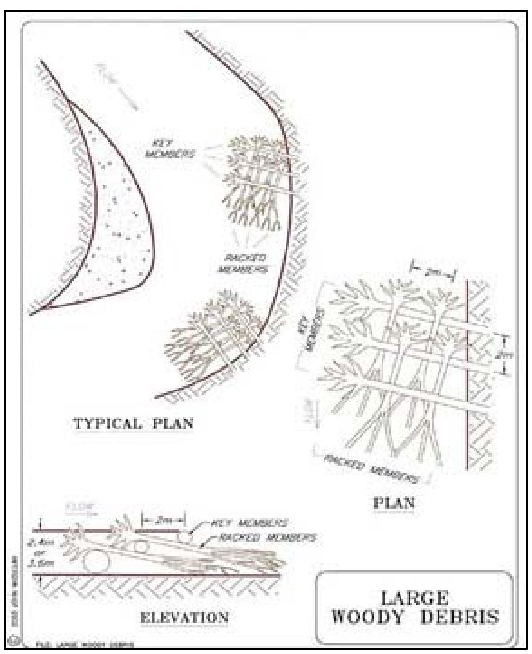

Figure 5.24 . Woody Debris

Placing LWD into streams is an increasingly popular technique to improve fish and wildlife habitat. Large woody debris projects can be divided into two categories; improving the habitat by increasing the amount of LWD in the stream, and using LWD to alter flow in some way to improve aquatic habitat.

Some specific objectives that can be accomplished by using LWD are the following: Create pool habitat, generate scour, increase depths through shallow reaches, divert flows away from the bank to reduce erosion, armor stream banks to reduce erosion, promote bar formation through induced sediment deposition, and increase instream cover and refugia (figure 5.24).

Large woody debris commonly placed into the streams can be categorized as three types: whole trees, logs, and root wads. A whole tree is a tree cut off at the stump with all or most of the limbs attached, including terminal branches. Logs are sections of the bole with all sections removed. Rood wads consist of the root portion of the tree and the section of the bole.

5.23.2. Lessons Learned. The primary engineering concern is to ensure that anchoring is adequate to hold the structure in place during the most extreme flow conditions. Tree species: cypress, cedar, redwood, and oak last the longest. A dry and cool climate prolongs the life of the LWD. The position relative to the water surface, frequent wetting and drying reduces life – continuously submerged wood lasts the longest. Soil contact: microbial digestion in soils limits life, but burial in anaerobic soils prolongs life almost indefinitely.

5.23.3. References

Derrick, David, L. (2005): *#6 Re-directive-Compressed*

Fischenich, Craig J. and Morrow, James V., Jr. (200): *Streambank Habitat Enhancement with Large Woody Debris*

McCullah, John (2004): *Environmentally-Sensitive Streambank Stabilization*

5.23.4. Case Studies. Large wood bundles have been placed in numerous scour holes in several side channels of the Middle Mississippi River (photograph 5.19)

Photograph 5.19. Wood Bundles

5.24. Boulder Clusters

5.24.1. Design Methodology. Stones placed in a flowing channel with the top of the stone set at an elevation slightly lower than the typical base-flow water surface elevation. When sited correctly, the accelerated flow over the tops of the stones will change from sub critical to supercritical flow, and further downstream back to sub critical (usually with a weak hydraulic jump). Downstream of the stones, standing waves and a V-shaped wake will form. The stones also provide resting areas and in-channel refugee for fish during high energy, high-flow events. The hydraulic jump can also help to entrain air and aerate the stream.

The crest elevations of the stones can also be placed at, or slightly above, the typical base-flow water surface elevation, which will split flow and result in a double eddy return flow pattern DS of the stone. However, these stones can now be used as perches for predators. Hydraulic Cover Stones are especially useful in sections of the stream with little in-channel structure, or vegetative cover, or undercut banks (figure 5.25).

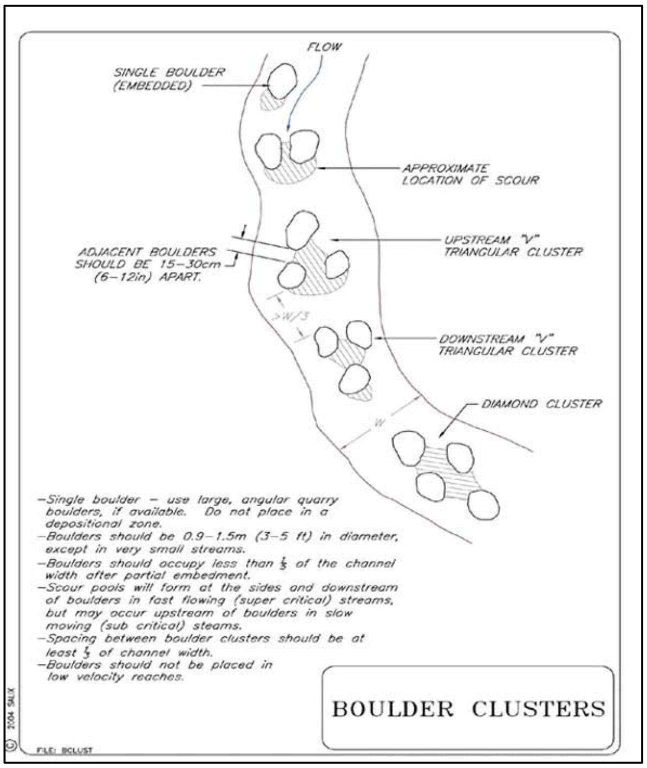

Figure 5.25. Boulder Clusters

5.24.2. Lessons Learned. Excessive scour can bury the boulder. The rock clusters block a large percentage of stream flow. It is possible for rock clusters redirect stream energy in unwanted direction. You can develop excessive deposition down stream of the cluster if not designed properly. If the rock cluster is too high, they can provide perches for predators and/or fishermen.

5.24.3. References

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McCullah, John (2004): *Environmentally-Sensitive Streambank Stabilization*

5.24.4. Case Studies. Eighteen Mile Creek salmon stream restoration, Newfane, NY (photograph 5.20)

Photograph 5.20. Boulder Clusters

5.25. Fish Lunkers

5.25.1. Design Methodology. L*U*N*K*E*R*S Little Underwater Neighborhood Keepers Encompassing Rheotactic Salmonids (Rheotactic - fish that prefer to face into the current)

A LUNKER structure, first developed and used in Wisconsin, is an engineered, overhanging-bank structure designed to provide habitat for aquatic fishes while providing bank stability. A LUNKER is typically 8 ft long, 1 to 2 ft tall, and 3 ft deep, constructed of hardwood (or concrete or plastic wood if numerous wet-dry cycles are anticipated), with an open front and ends. The toe of the outer bank of the stream is leveled, then the LUNKER is placed on the level bed and 0.5 inch, x 7 ft long sections of rebar are driven through pre-drilled holes and into the stream substrate, anchoring the LUNKER to the stream bed. The area bankward of the LUNKER is filled with riprap, and either stones, or soil and a circular coir fiber roll are positioned on top of the LUNKER. Concrete-roofed LUNKERS can be used as fishing platforms in handicapped-accessible facilities (figure 5.26).

5.25.2. Lessons Learned. Design deficiencies can occur if the LUNKER fills in with sediment, left high and dry, or exhibit scouring of the foundation materials resulting in collapse. Functioning LUNKERS require: (1) sufficient velocities to scour overhang area; (2) The foundation to be reinforced; and (3) the low-flow water surface elevation to be on the header board.

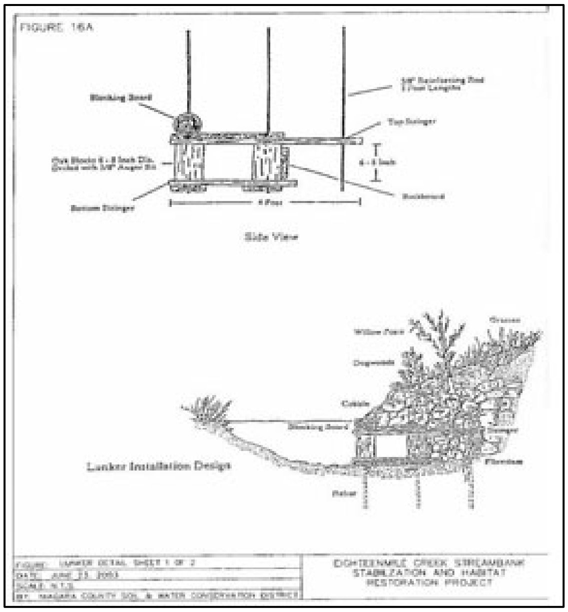

Figure 5.26. Fish LUNKER

5.25.3. References

Derrick, David, L. (2005): *#7 Resistive-Compressed*

5.25.4. Case Studies. Eighteen Mile Creek salmon stream restoration, Newfane, NY (photograph 5.21).

Photograph 5.21. Fish LUNKER

Aeration

CHAPTER 6

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AERATION

6.1. Resource Problem

Water can hold a limited amount of oxygen. That is determined by atmospheric pressure, temperature and salinity. In a natural setting, oxygen is added to water by atmospheric diffusion at the surface, by wind circulation and by photosynthesis (oxygen produced by phytoplankton or algae). Oxygen is involved in the regulation of metabolic processes of most aquatic communities and organisms, and therefore is one of the most significant chemical substances in water. The concentration of dissolved oxygen is perhaps the most important chemical quality which affects the distribution of fishes. Oxygen depletion reduces the quantity and quality of habitat for fish and fish food organisms. It causes physiological stress in fish and often leads to the development of imbalanced fish communities dominated by relatively undesirable species.

A number of conditions may develop which result in oxygen depletion. Oxygen depletions are typically associated with some of the following conditions:

Hot, cloudy, still weather is common during the summer months. High water temperature (86 degrees F or greater) reduces oxygen holding capacity. Cloud cover limits available light, slowing or halting photosynthetic oxygen production. No wind stops circulation in backwater and pond areas and restricts surface diffusion of atmospheric oxygen. Warm water increases fish consumption of oxygen by accelerating their metabolic rate. Fish are cold blooded; therefore, body temperatures and activities are regulated by water temperature. On the other extreme, however, oxygen demand is of particular concern in the winter months when primary productivity is low and re-aeration is restricted due to ice cover.

Sudden death of phytoplankton or algae bloom may result from insufficient light (e.g. cloud cover) for photosynthesis. Oxygen is consumed or depleted when dead phytoplankton/algae decay. During the nighttime hours, a dense phytoplankton bloom can remove all oxygen from the water for respiration (to breathe) alone. When a bloom crash occurs, the water appears to have become “black” or clear overnight.

Pond stratification or turnover. During summer months in deep water (8 feet or greater), the upper 4-6 feet of the water column warms quickly and becomes less dense or lighter than deep water. Because the upper layer is warmer and lighter, it does not mix with the cool deep water. The cool water near the bottom becomes stagnant; oxygen is depleted and toxic compounds may be produced by bacteria and decaying organic matter. The deep layer remains unoxygenated (anoxic) because of stratification (layering). A sudden, heavy rain (2-3 inches or greater) or a strong cold front can rapidly cool and/or mix (wind turbulence) the upper layer. Now the cooler or circulating upper layer sinks or mixes and causes the deep anoxic layer to rise above or combine with the surface water. That depletes or reduces oxygen in upper waters where fish are being cultured.

> **Organic waste decomposition**. When fish biomass becomes large in areas, waste and organic loads (ammonia, nitrate, feces and uneaten feed) can become high. Wastes and organics will decompose. That requires oxygen, often more than is available in certain bodies of water. Also, high waste loads can stimulate an algal bloom too dense to be supported by the water body (discussed above).

These situations can occur alone or in interrelated combinations. As just discussed, conditions may develop which remove oxygen from water faster than natural processes can replace it. When they occur, emergency or supplemental aeration may be required to bring oxygen back up to tolerable or safe levels.

6.1.1. Environmental Impacts. Oxygen is vital to all metabolic processes of aquatic communities and organisms. Logically, the manipulation of the oxygen content of lakes, rivers, reservoirs and streams can have a profound effect on their chemistry and biota. Therefore, adverse or beneficial effects, other than the improvement of habitat for fishes, may result from destratification, aeration, and oxygenation management techniques.

The principal adverse effects of destratification are related to the mixing action of the technique. Destratification transforms a lake into a nearly isothermic water mass, with a temperature close to the normal surface water temperature. If the surface water temperature is too high, coldwater fishery habitat will be eliminated.

Turbulence created by the destratification processes may cause resuspension of bottom sediments. If the sediments that are resuspended exert a particularly high oxygen demand, dissolved oxygen depletion may result, especially if the destratification equipment is inefficient and cannot compensate for the increased oxygen demand. If the destratification is improperly timed in relation to algal blooms, existing oxygen deficiencies can be aggravated.

Hypolimnetic aeration is more limited in controlling algal blooms than those realized by whole lake mixing, but the risk of adverse effects is less. Provided that the equipment used is properly designed, possible nitrogen supersaturation and resuspension of toxic contaminates are the only potential adverse effects that may result from hypolimnetic aeration.

Some physical hazards to humans may be associated with aeration efforts. Extensive open-water areas that result from winterkill prevention techniques create a danger, especially to snowmobilers. Mechanical aeration devices can be a hazard to swimmers and boaters. The impellers on mechanical agitators can severely injure swimmers, and the presence of such devices can obstruct navigational lanes.

6.2. Design Methodology and Criteria

6.2.1. Aeration Techniques. Artificial aeration and oxygenation techniques have been developed to help alleviate dissolved oxygen depletions in lakes and streams. Such techniques can be used in a variety of situations to improve conditions in aquatic habitats. The application of aeration techniques increases dissolved oxygen concentrations that have become unacceptably low. It is important to keep in mind that most artificial aeration techniques can only be applied to limited areas due to cost and scaling issues.

Aeration techniques can be divided into three major categories: destratification (whole-lake aeration); aeration of the anoxic lower stratum (hypolimnetic aeration); and supplemental stream aeration. Aeration techniques are used to alleviate fishery problems associated with anoxic or near anoxic conditions in bottom waters or under ice. Aeration affects the biological, chemical, and physical characteristics of a lake or stream and thus many management implications.

Of the many aeration techniques, supplemental instream aeration and winterkill prevention may be those most immediately applicable in the Upper Mississippi River System. Supplemental instream aeration may be a particularly important management alternative if significant increases in organic loading occur within the Upper Mississippi River basin. Winterkill techniques can be put to immediate use.

Destratification and hypolimnetic aeration may have limited value on the Upper Mississippi River System. However, if hydroelectric facilities are developed at the navigational dams, or if modifications of dams are made in conjunction with the development of a deeper navigational channel, the river system might be altered to the point that some degree of thermally induced density stratification occurs. If oxygen depletion results, the use of remedial destratification or hypolimnetic aeration systems may be required.

6.2.1.1. Destratification. Destratification can be achieved through air-lift circulation or pumping. This technique is used in fishery management as a method for restoring habitat losses caused by anoxic conditions in the hypolimnion of eutrophic, stratified lakes and reservoirs and to prevent winterkills.

Treatment of winterkill lakes by destratification techniques can be approached by two methods: Destratification can be implemented before ice formation to increase the lake’s oxygen reserve and reduce the amount of an oxygen consuming, decomposable organic matter; or a destratification apparatus can be used during ice formation with the intent of maintaining large holes in the ice that will facilitate surface aeration and provide strong mixing currents that will circulate oxygen throughout the water mass.

Diffused –air mixing, or fine bubble aeration, is the most popular method used to disrupt destratification. Ease of installation and simplicity of operation are the principal advantages over mechanical mixing. Aeration of the water column (in addition to turbulence-induced aeration at the air-water interface) is a further beneficial feature of this technique.

A number of designs for diffused-air mixers have been developed. The systems pipe compressed air to a release apparatus located near the lake bottom in the area of greatest depth. Some of the release apparatus designs used are perforated pipes, diffuser stones or air cannons.

Diffused-air mixing aeration equipment requires electricity or fuel powered engines to operate. Therefore, this type of aeration is usually not practical in a river or backwater environment.

6.2.1.2. Hypolimnetic Aeration and Oxygenation. Hypolimnetic aeration and oxygenation is a method of adding dissolved air and oxygen to the hypolimnion of a water body without disturbing the thermal stratification. The process differs substantially from aeration by destratification and is used when maintenance of cold oxygenated hypolimnetic water is desired.

Air injection systems can be categorized as full air-lift or partial air-lift designs. In full air-lift systems, air is injected near the bottom of the aerator. As the air rises to the surface, it lifts water with it. The air and water then separate and the water returns to the hypolimnion. Partial air-lift designs operate similarly, except that the air and water are allowed to separate below the surface of the water. Water is allowed to return to the hypolimnion and air is released through a vent pipe.

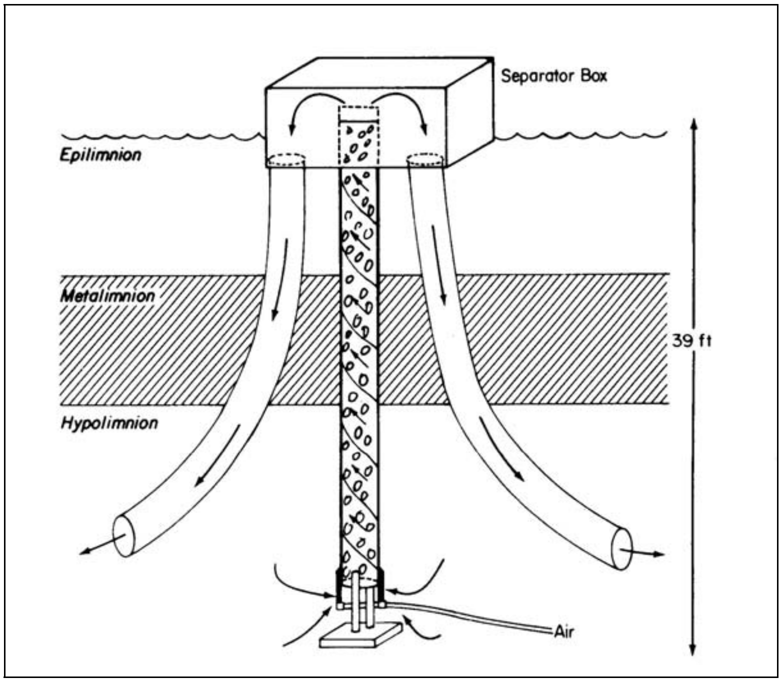

Figure 6.5. Hypolimnetic Aerator Design

6.2.1.3. Supplemental Instream Aeration. Supplemental instream aeration is the addition of air to a flowing stream to maintain the dissolved oxygen content of the water at an acceptable level. Supplemental instream aeration can be provided by using any of several devices and techniques. Mechanical and diffuser aerators are two designs that have been used for instream aeration.

The mechanical surface aerators most commonly used have an impeller that draws water to the surface and casts it out by centrifugal force. A zone of intense turbulence is created to entrain and absorb air.

Diffuser aerators are similar to those used in destratification assemblies. The headers are usually perforated pipes placed parallel to each other in the stream bed or perpendicular to the flow. The size of the device needed depends on the concentration of oxygen-demanding waste in the stream and the characteristics of the site.

Since mechanical and diffuser aerators both require some type of synthetic power supply, supplemental instream aeration may not be practical in a river or backwater environment.

6.2.2. Aeration Costs. The major capital costs associated with a destratification system and hypolimnetic aeration systems are air compressors, supply lines, and diffusers. Operating costs will be primarily for electricity, making wind-powered aeration systems much more economical. Figure 6.2 outlines the selection process for determining the best type of aeration system to be used.

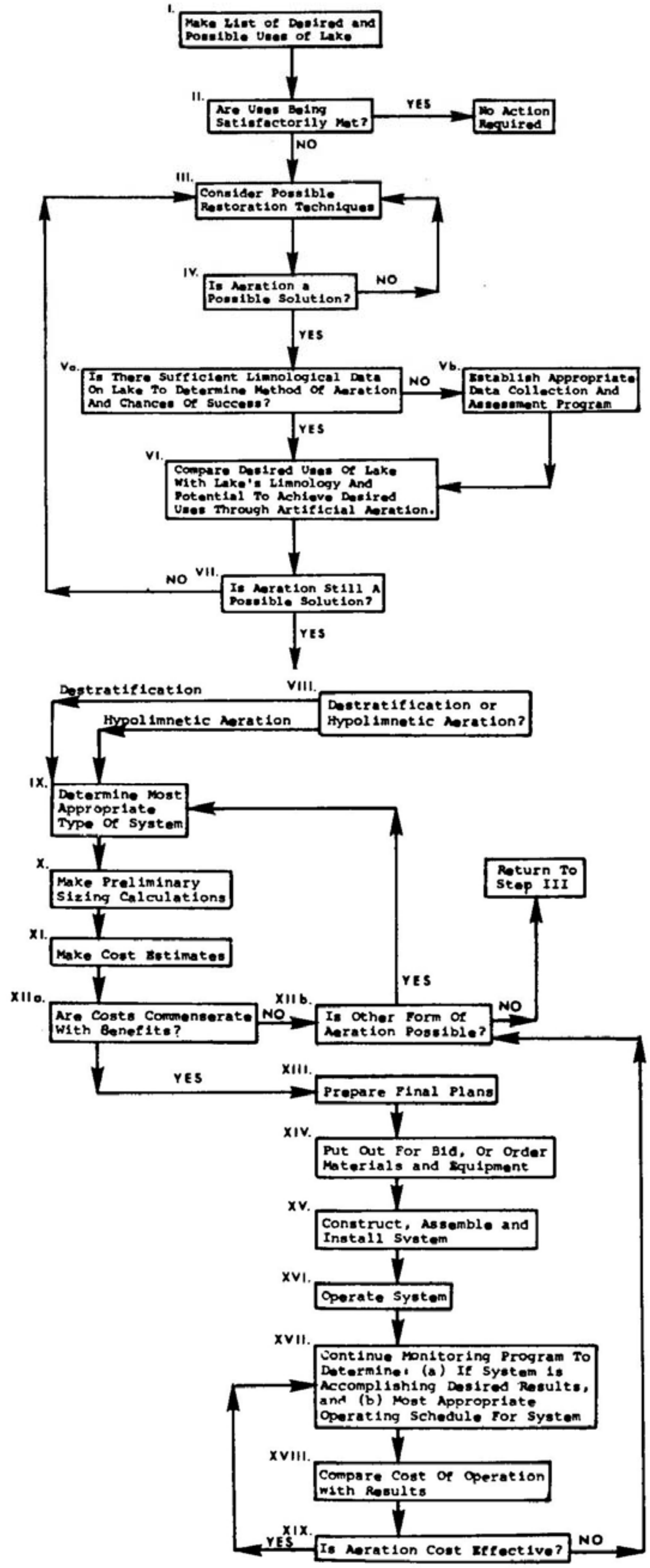

Figure 6.6. Aeration Cost Diagram

6.2.3. Aerators. Aerators work by increasing the area of contact between air and water. Aerators also circulate water so fish can find areas with higher oxygen concentrations. Circulation reduces water layering from stratification and increases oxygen transfer efficiency by moving oxygenated water away from the aerator.

Electric or mechanical aeration is used to place as much oxygen into contact with water as economically practical. That is normally accomplished by mixing large quantities of water (both volume and total surface area) with atmospheric oxygen.

Surface spray or vertical pump aerators have a submersible motor which rotates an impeller to pump surface water into the air as a spray. They float, are lightweight, portable and electrically powered. They are usually of little use in large bodies of water because of relatively low oxygen transfer rates and their inability to create an adequately large area of oxygenated water.

Pump sprayer aerators are found on many fish farms. Most are powered by a tractor power takeoff or electricity. Pump sprayer aerators are equipped with either an impeller suction pump, an impeller lift pump, or a turbine pump. Most discharge directly through a manifold which has discharge slits on top and outlets at each end. Water is sprayed vertically through the discharge slits and from each end of the manifold. This type directs oxygenated water along a bank line where distressed fish often go. Pump sprayers typically have no gear reduction which reduces mechanical failure and maintenance.

Fountain aerators are a popular choice when a decorative aerator is desired. Fountains splash the surface of the water and help control surface algae and weeds but do not aerate down to the bottom in deep waters (figure 6.3).

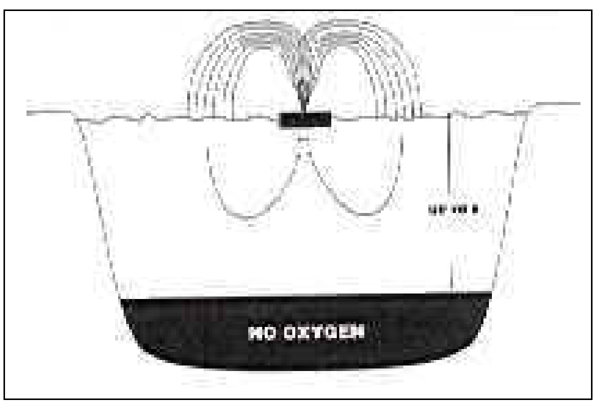

Figure 6.7. Fountain Aerator

Paddlewheel aerators are typically used on farm ponds and made from truck differentials and vary with drum size and configuration, shape, number and length of paddles. Units are powered by power takeoffs or driven by self-contained diesel engines. The self-contained units are usually on floats and attached to the pond bank or held in place by steel bars secured in the bank or pond bottom. Some paddlewheel units are electrically powered as well.

Diffuser aerators operate by low pressure air blowers or compressors forcing air through weighted aeration lines or diffuser stones releasing air bubbles at the water's bottom or several feet below the water surface. Efficiency of oxygen transfer is related to the size of air bubbles released and water depth. The smaller the bubble and the deeper it is released, the more efficient this type of aerator becomes (figure 6.4).

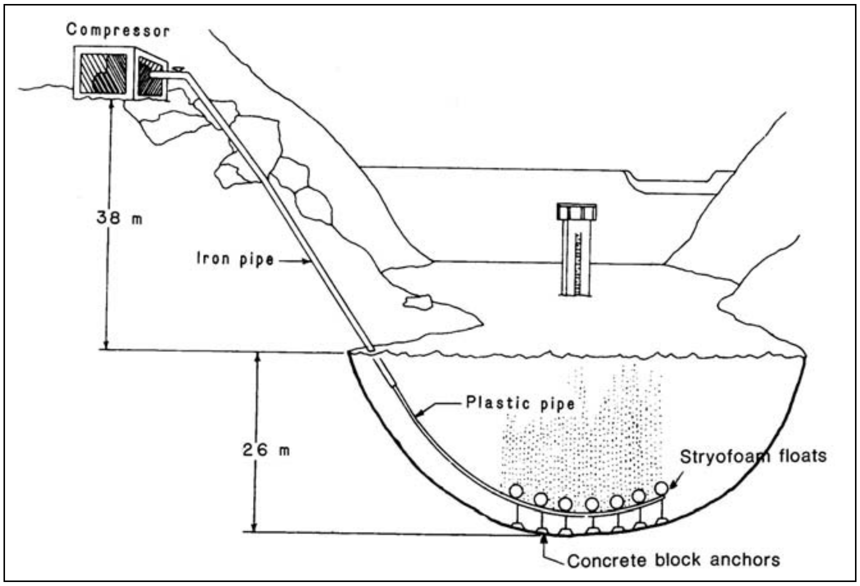

Figure 6.8. Diffuser Aerator

Propeller-aspirator aerators consist of a rotating, hollow shaft attached to a motor shaft. The submerged end of the rotating, hollow shaft is fitted with an impeller which accelerates the water to a velocity high enough to cause a drop in pressure over the diffusing surface which pulls air down the hollow shaft. Air passes through a diffuser and enters the water as fine bubbles that are mixed into the water by the turbulence created by the propeller. These types of aerators are electrically powered.

Wind-powered aeration devices may be a viable alternative if oxygen depleted water masses are in remote areas where electrical and gasoline power sources are unavailable or where their installation is uneconomical. However, wind-powered, artificial aeration system must possess certain basic qualities. The system must be relatively cheap. In order for wind-power to be an economical energy alternative, the system must be available at a low price. The design must also be simple and it must be constructed out of inexpensive and readily available components. Since the system will be installed at remote sites, it must be easy to transport and easy to erect. This means that the system must be simple to assemble and disassemble. The system must also be structurally and mechanically able to withstand high winds and extreme temperatures with only a minimum of maintenance.

Supplemental in-stream aeration. There are physical ways to circulate waters with low flow by placing alternating structures within the stream to increase the atmospheric processes of aeration.

Other aeration techniques are available without the introduction of pumps or other apparatuses to a body of water. Deeper water and improved flows reduce the dissolved oxygen problems that reduce habitat quality. Through dredging, increases in flows improve oxygen exchange between the spring-fed areas and main water bodies. Deepwater areas improve overall aquatic habitat quality and provide ingress and egress to oxygen deficient-prone areas. Flow increase in side channel dredge areas increases the introduction and mixing of more oxygen-rich water into low-velocity areas. By providing entrance and exit channels for fish, trapping and winter/summer kill potential can be significantly reduced in nonflowing water bodies.

The best way to deal with low oxygen is to take action before a problem develops. Good management is vital to the overall quality of aquatic habitat.

6.2.4. Gravity Flow Aeration . Gravity flow techniques provide aerated water to downstream water bodies. These projects usually consist of a dredged channel with some type of control structure such as a gated conduit to regulate the quantity of flow that is conveyed into downstream water bodies. The size of these structures is based on the following items:

- **Water Quality Requirements in Downstream Water Bodies.** The amount of water needed must provide adequate dissolved oxygen during critical times of the year, but not reduce water temperatures to levels that are too low. Usually, a hydraulic residence time in the downstream backwater that exceeds 10 days is required.

- **Maintenance Considerations Related To Debris Plugging.** In some situations small debris can be flushed from the conduit entrance or from the outlet channel, by increasing discharge levels and velocities in the system. This usually requires a flow capacity that is significantly higher than that required for aeration.

- **Economics.** Smaller structures are generally cheaper, however unknown flow requirements in the future may require that a larger structure be constructed to cover all flow requirements.

- **Controlling and Maintaining Debris.** This is a primary consideration in designing the inlet to these structures. Trash racks, wooden piles, sheep and cattle fencing, and a number of other techniques have been used to prevent debris from plugging these structures. Debris can be large (trees and logs) or small (floating vegetation).

It is important to keep in mind however, that introducing water to an area may also introduce sediment. This may be minimized by only opening the control structure during low flow periods, winter months or when absolutely necessary for aeration.

6.3. Lessons Learned

Blackhawk Park. The ultimate purpose or goal of the Blackhawk Park project was to preserve and enhance existing fish habitat. The backwater lakes and sloughs at Blackhawk Park were identified as important fishery habitat with multi-State importance. The purpose of the project was to convert 258 acres of backwater lakes from seasonal to year-round fish habitats, annually contributing an additional

20,000 fish to the boundary waters of Wisconsin, Minnesota, and Iowa. Over the 50-year project life, an estimated 1 million fish would be produced and dispersed to the waters of the three States. Several of the side channels that historically supplied water to this backwater complex were obstructed by the construction of roads to the park and to adjacent private developments. These obstructions resulted in the loss of freshwater (well-oxygenated) flows to these backwater areas during most of the year. The lack of freshwater flow resulted in dissolved oxygen (DO) depletion problems in these backwater lakes and sloughs. Habitat restoration efforts in the Blackhawk Park area began prior to the creation of the EMP.

The USACE constructed a channel to provide fresh water to Green and Peck Lakes in the early 1980's. The Blackhawk Park habitat project under the EMP was a continuation of this effort to provide flows to the backwater complex lying east of the park boundaries. The project included the installation of three culverts in a private driveway, the construction of channels from the main channel to Long Slough, and the dredging of two sediment traps. The major action was the construction of 7,000 linear feet of channels from the main channel to the head of Long Slough. The channels provide freshwater flow to Long Slough in order to alleviate oxygen depletion problems.

The channel depth and size should have been increased to account for sediment deposition, debris, and ice blockage. Although the channels continue to provide flow to downstream backwaters, the amount of flow is marginal and can be greatly reduced by ice formation in the winter.

Big Timber. Big Timber HREP project was initiated in response to a rapid accumulation of sediment that had greatly reduced the quantity and quality of the wetland habitat in the low swales present on Big Timber Refuge and aquatic habitat in the deep areas of the interior channels. In the shallow areas of the interior channels, dissolved oxygen values had fallen to critical levels and fish species diversity had decreased.

The Big Timber HREP project was hydraulically dredged and mechanically excavated to enhance aquatic habitat. The objective was to restore both deep and shallow aquatic habitat, improve levels of dissolved oxygen during critical seasonal stress periods, and provide year-round habitat access. The Big Timber project was successful in its effort to improve levels of DO during critical seasonal stress periods. The project was highly successful in achieving this goal during the critical winter months where supersaturated conditions were often observed.

Finger Lakes. Design for a wide range of flow conditions. The gated conduits that were used at this site were sized to provide up to 50 cubic feet per second (cfs) to each of the downstream Finger Lakes. A Biological Response study that was conducted after the project was constructed indicated that the required winter flow was on the order of 5 cfs or less, about 1/10th the capacity of the conduits. However, recommended summer discharges are on the order of 40 cfs, which is near the maximum flow of the conduit. Furthermore, the Fish and Wildlife Service often flushes the pipes by using their full capacity to clear out small debris from the entrance and outlet channels. The important thing is that being able to provide a range of flow rates is desirable at aeration projects.

Spring Lake - Dye Dispersion and Fish Movement in Response to Increased Winter Inflow at Spring Lake. An environmental enhancement project for the lake was completed in 1999 as part of the Upper Mississippi River System Environmental Management Program. The project included construction of a gated inlet in the perimeter levee of the lake to allow for the inflow of oxygenated river water into the lake during winter periods of low dissolved oxygen to help prevent fish kills. The gates are closed during other times of the year in order to prevent sediment from entering the lake.

A fish kill occurred in both the upper and lower portions of Spring Lake during January 2001. During this time, one gate was open 15 cm (6 in) and low dissolved oxygen (DO0 concentrations were recorded by an in-situ water quality monitoring instrument deployed in the lower lake. In an effort to prevent future fish kills the following dye studies were performed.

Dye dispersion and fish movement were monitored during February 2005 by U.S. Army Corps of Engineers, Rock Island District following an increase in inflow to Spring Lake. The results from a similar dye study performed in 2002 indicated that with a 25 cm (10 inch) gate opening, reoxygenation of the lake occurs slowly, with the dispersal pattern favoring the deeper portions of the lake. The primary purpose of the present study was to determine how inflowing oxygenated water disperses, both temporally and spatially, throughout the lake during the winter under ice cover while utilizing a gate opening of 91 cm (3 feet). A single slug injection of Rhodamine WT dye was dispensed in the inlet structure and tracked over a period of thirteen days as it dispersed throughout the lake.
An additional objective of the study was to track the movement of 20 radio-tagged centrarchids in response to the increased inflow. Fish movement was determined during three tracking events over an 11-day period.

As anticipated, with the larger gate opening, the dye traveled through the lake in a shorter period of time. With a gate opening of 91 cm (3ft) in 2005, inflowing water dispersed throughout Spring Lake faster and more completely than was observed during a similar study in 2002 when the inlet structure gate was open only 25 cm (10 in). A comparison of dye analysis results from samples collected on the sixth day following injection during both studies show that the dye traveled more than twice the distance during 2005 compared to that observed in 2002. The dye traveled 1,125m (3,691 ft) in 2002, for an average velocity of .22 cm/sec while in 2005 it traveled 2,375 m (7,792 ft) for an average velocity of .46 cm/sec.

Movement of radio-tagged centrarchids (black crappies and a bluegill) indicated the fish were not adversely impacted by the increased gate opening. Initial concerns that the fish may be “flushed” from the area did not materialize. The velocity in the vicinity where most fish were located throughout the study increased from 0.16 cm/sec (prior to increasing the gate opening) to 0.45 cm/s (after increasing the gate opening). The 0.29 cm/s increase in velocity was apparently insufficient to cause the fish to disperse from the area.

Although not practical, the breach of a levee or dam is another way to introduce dissolved oxygen to an area with low levels of oxygen. For example, in 1968 Spring Lake was divided by the U.S Fish and Wildlife Service into an Upper Spring Lake and Lower Spring Lake. When the Lower Spring Lake levee was breached on the west and south sides by the 1965 flood, ingress and egress of other species from the river provided more diversity in aquatic life. This breach also provided the lake with an abundant supply of dissolved oxygen. With the repair of the levee in 1991, flow of dissolved oxygen through the Lower Lake was greatly diminished. This lack of dissolved oxygen is a limiting factor in the current fishery.

Water control structures play a role in the amount of dissolved oxygen contained in a body of water. The construction of inlet structures and gatewell structures allow for flow and dissolved oxygen dissipation. Water control structures can be used to help control and maintain water quality in backwaters and side channels.

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FLOODPLAIN RESTORATION

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7.1. Resource Problem

Floodplain habitats are integral components of large river ecosystems because of the seasonal flood pulse that inundates them and connects them to the river. Many species of plants and animals are adapted to this flood cycle and take advantage of habitat and food resources as they are made available. Many important sediment and nutrient transfers also occur when floodplains are inundated. Floodplain habitats throughout the Upper Mississippi River System (UMRS) have been altered for many reasons. In northern river reaches, dams spread water across low elevation floodplain areas to greatly increase aquatic habitat connectivity in the floodplain. Floodplain restoration in the north is a mix of protecting some areas with islands, connecting isolated backwaters, and restoring tributary channels. In southern river reaches the floodplain is much more developed for crop production and flood protection, and is thus much more isolated from the river. Floodplain restoration in southern reaches includes a mixture of water level manipulation in management areas, wetland/habitat management in leveed areas (e.g., WRP, CRP, etc.), or restoration of agricultural areas to aquatic, floodplain forest and prairie habitats. Restoration of privately-owned floodplain areas requires landowner cooperation or acquisition of real estate interests from willing sellers and donors. Some floodplain restoration methods include

- Topographic Diversity
- Potholes or Perched Wetlands
- Mast Tree Planting
- Native Grass Planting
- Wetland Species Planting

7.2. Topographic Diversity

Increased floodplain water table elevation can result in the elimination of flood intolerant tree species that require a dry root zone. Improving topographic diversity simulates the ridge and swale topography of the natural floodplain by using material dredged from the channel. This newly elevated land area may then be planted with oaks and other mast trees. At Johnson Island, an experiment was conducted in 2001 where hydraulically dredged material was placed in and around existing mature trees. Care should be taken if this method is used as tree mortality may occur depending on the type and age of trees.

Most work on topographic diversity on the UMRS has occurred in conjunction with island creation or dredge management activities. Nonetheless, the considerations on topographic diversity for floodplain restoration are similar. Improving topographic diversity simulates the ridge and swale topography of the natural floodplain.

The severing of floodplains from rivers by levee systems also stops the processes of sediment erosion and deposition that regulate the topographic diversity of floodplains. This diversity is essential for maintaining species diversity on floodplains, where relatively small differences in land elevation result in large differences in annual inundation and soil moisture regimes. These differences regulate plant distribution and abundance (Sparks, 1992).

7.2.1. Design Methodology

Potential Environmental Benefits. As proposed, this measure could be achieved through either the modification of existing geomorphic surfaces or through the creation of new ones. Increased topographic diversity in turn, would increase habitat diversity and benefit targeted species. It could also potentially serve to improve conditions for the recruitment and development of riparian vegetation. Improving riparian conditions would benefit wildlife that depends on this type of habitat.

Potential Constraints. During the summer months flows are relatively high due to the un-natural containment systems of the locks and dams. Thus, the impaired flow regime does not resemble the unimpaired regime either in timing, magnitude, or duration of peak flows. This has implications for both the design and possible functioning of floodplain surfaces that might be created.

The principal constraint to effectiveness will be the prescribed flow regime. Unless a complementary flow regime is implemented, the created or modified topographic surfaces will not function as habitat. Secondary constraints include the availability of substrate with which to create surfaces and the potential short-term water quality impacts of in-channel construction.

Design Considerations and Evaluation. If new benches are created or floodplain surfaces modified, they require bank protection to prevent erosion. Bank protection could be accomplished through the addition of rock (i.e., rip-rap) imported from outside the area or with bioengineering approaches (willow mattresses, ground cover, etc).

It is assumed that the modified surfaces or benches would be constructed at elevations corresponding to different magnitudes of flow, simulating a natural floodplain setting. It is conceivable that stage-discharge relationships corresponding to unimpaired flood flows could be developed and used to design the geomorphic restoration. However, the existing flow regime does not often resemble the unimpaired hydrograph.

If the benches and flow regime approximated a natural condition, it would probably represent a scaled-down version of the former alluvial system. That is, it would be an alluvial system within the entrenched channel operating on an impaired natural flow regime. Although not difficult to envision, it would likely prove difficult to design as a self-regulating system. Probably the most challenging aspect would be estimating and negotiating the prescribed flow regime.

Any proposed action would include planting or otherwise establishing vegetation on the benches and is best coordinated with riparian vegetation enhancement. It is assumed that the vegetation on the benches would attempt to simulate a natural riparian successional pattern. The vegetation on different geomorphic surfaces would correspond to flood exposure. Reference conditions would be needed; specific items to consider include erosion control, desired future riparian vegetation, control of exotics, and relationships between flow and vegetation.

The effects of the geomorphic restoration on downstream and upstream geomorphic processes would need to be evaluated. If the emphasis were on modifying surfaces that already exist, the potential effects would probably be relatively insignificant. If entirely new surfaces were created, they would change flows and geomorphic processes in an already unstable system. Therefore, the latter would probably be more risky and would likely require more detailed evaluation.

Another major issue to consider in the design would be the potential response to extreme peak flow events. During events of magnitude, massive erosion on the created or modified geomorphic surfaces could occur. Measures of effectiveness could include mapping of created surfaces and associated vegetation and population surveys of targeted fish species, (Sparks). The main uncertainties with this measure are the flow regime requirements; availability of substrate for geomorphic construction; effects of geomorphic constructions on channel behavior; and effects of peak flows.

This is a conceptually appealing feature but it is probably best to combine it with side channel creation and enhancement. Even better would be combining topographic and geomorphic restoration with riparian restoration and looking at both together. This would facilitate evaluation of alternative flow regimes that would support restoration proposals. However, even before all that, the approach to restoration needs to be clarified. Is the intention to engineer restoration or to restore processes so that the stream naturally restores itself?

7.2.2. Lessons Learned. When constructing topographic features, it is imperative to mimic the elevations currently in the nearby area and to consider the natural slope of the river from the main channel to backwaters. In general, higher bermed islands or floodplain features work better next to channels because higher ridges are better able to withstand wave and wind action without being overtopped or eroded, while further off the main channel and away from high fetch areas, lower ridges may be more stable.

Proper placement of the feature in relation to current or wave action is important to ensure success. Topographic features that are misplaced relevant to current may actually increase undesired events such as increased sedimentation in backwaters as the current may bring in sediment-laden water which is retained by the island, thus converting the backwater into a settlement basin, (Orville Facilities).

7.2.3. References

Orville Facilities Relicensing Efforts, Environmental Work Group, Draft Narrative Reports for Resource Action Discussion, *Modify or Reconstruct Trenches in the Feather River Channel to Enhance Spawning and Rearing Habitat*, 05 February 2004.

Protecting Riparian Areas: Farmland Management Strategies Soil Systems Guide, Barbara C. Bellows, NCAT Agriculture Specialist, ATTRA - National Sustainable Agriculture Information Service, March 2003

Environmental Assessment, Material Placement Site for Maintenance Dredging, Johnson Island, Mississippi River Pool 18, Des Moines County, Iowa, July 1995, Revised May 1996

Richard E. Sparks, *Risks of Altering the Hydrologic Regime of Large Rivers* Pages 119-152, 1992, Illinois Natural History Survey

7.2.4. Case Studies

Weaver Bottoms, Pool 5. The islands are effectively separated from the water table thus making it nearly impossible for mast tree growth. Additionally, swale habitat that is too low may be lead to infestations of undesired invasives, such as reed canary grass and purple loosestrife.

Lansing Big Lake, Pool 9. A channel close-off was constructed with sand that included a ridge and swale feature. The ridges were built higher than the surrounding land features. As a result, the river cut new channels through the close-off, thus demonstrating the importance of carefully considering ridge elevation in design and the need for fine materials to help ensure stability.

Pool 8 Islands Phase II. During the spring flood of 2001, the constructed ridges remained above the water surface, however, the current eroded around them, leading to the loss of many ridges. A similar situation occurred in Lansing Big Lake where a channel close-off was constructed with sand. The close-off included a ridge and swale feature. The ridges were built higher than the surrounding land features. As a result, the river cut new channels through the close-off, thus demonstrating the importance of carefully considering ridge elevation in design and the need for fine materials to help ensure stability.

Johnson Island, Mississippi River Pool 18, Des Moines County, Iowa

7.3. Potholes or Perched Wetlands

Potholes are constructed to create open water habitat by excavating deeper pockets within a mudflat. These pockets fill with water and allow for the growth of submergent aquatic vegetation, drawing in wildlife that utilizes that habitat. Potholes therefore add to the biotic diversity of the project, in both the plant and animal communities. Potholes may be considered perched wetlands if little to no interaction with the groundwater occurs. This makes the pothole dependent on surface flows for moisture.

Material excavated to create potholes may be used for berm construction or to create topographic diversity. Please refer to the previous section for additional information regarding topographic diversity.

7.3.1. Design Methodology. Potholes can be constructed through mechanical excavation or through the use of explosives. Empirical studies by the Bellevue LTRM at Potters Marsh HREP indicate that, if designed properly, there is no difference in usage by waterfowl between the two construction methods. This study indicated that pothole usage was linked to the amount of cover in the immediate vicinity of the pothole, where potholes with the best proximate cover saw the most usage by migrating waterfowl, and wading birds.

If the potholes are mechanically excavated, the borrow material can be used to construct berms. These berms can be used to reroute local hydrologic patterns or as topographic diversity to encourage diverse species growth within the project area. If borrow material is needed for a project, designers should consider incorporating pothole designs into the project, thereby gaining habitat benefits through both borrow and placement activities.

Potholes are more effective from a habitat perspective if many smaller potholes are constructed in close proximity. Potters Marsh HREP constructed many, smaller potholes. The total surface area at the 7-year performance evaluation was 8.3 acres, with most individual potholes less than 0.75 acres in size. Cottonwood Island HREP constructed three potholes, two 1-acre potholes, one ¾-acre pothole, and two ½-acre potholes were mechanically excavated. The larger potholes constructed at Cottonwood Island HREP have been used by amphibians, great blue herons, deer, and turkeys, but not waterfowl. Potholes constructed at Potters Marsh HREP are utilized by migrating waterfowl for nesting and brooding. Smaller, more frequent potholes may offer more cover, as they have more bankline for the volume.

Though smaller, more frequent potholes are desirable, each individual pothole should be larger than 0.1 acres in surface area. The potholes constructed at Big Timber, 0.03-0.08 acres each, were primarily used as cover for predators and are not considered desirable habitat.

Pothole side slopes should be gradual, no steeper than 3V:1H. Steep side slopes are conducive to predators, but not for brood rearing or other habitat uses. Pothole depth varies from 3 feet to 8 feet deep. Depth does not appear to be a limiting factor for pothole usage by migrating waterfowl. The shallowest potholes, at 3-4 feet in depth, were constructed at Potters Marsh HREP, where migrating waterfowl have successfully utilized the feature. If fish habitat is desired from the pothole, depths should be sufficient for overwintering.

7.3.2. Lessons Learned . If borrow material is needed for other project features, potholes should be considered for additional habitat benefits. The side slopes should be gradual. Multiple smaller potholes provide more cover than one larger pothole, and thus may provide more habitat value. Potholes less than 0.1 acres in surface area and those with steep slopes serve as cover for predators and should be avoided.

Terracing of the side slopes of larger potholes does not appear to be a cost effective practice. After a few years, the terraces erode into the pothole, leaving a bowl-shaped depression similar, if not identical, to the shape of potholes created by excavation or explosives.

Potholes experience some sedimentation and should be constructed deeper than needed to account for this. For waterfowl use, potholes 3-5 feet in depth were sufficient at Potters Marsh. However, at that depth it is possible that the pothole would freeze to the bottom in the winter. If it is anticipated that fish would be present in the project area over the winter months, potholes should be a minimum of 8 feet deep to prevent them from freezing through the entire depth.

Explosives regulations are prone to frequent change. It may not be possible to obtain permits to create potholes through the use of explosives. Designers should check permitting requirements in the early stages of feasibility if explosives are proposed.

7.3.3. References

US Army Corps of Engineers, Rock Island District (USACE, Rock Island), *3-Year (YR) Post-Construction Performance Evaluation Report For Cottonwood Island Habitat Rehabilitation and Enhancement Project*, June 2001.

USACE, Rock Island, *3-Year (YR) Post-Construction Performance Evaluation Report For Princeton Refuge Habitat Rehabilitation and Enhancement Project*, November 2001.

USACE, Rock Island, *7-Year (YR) Post-Construction Performance Evaluation Report For Potters Marsh Habitat Rehabilitation and Enhancement Project*, October 2003.

USACE, Rock Island, *9-Year (YR) Post-Construction Performance Evaluation Report For Big Timber Refuge Habitat Rehabilitation and Enhancement Project*, June 2001.

USACE, Rock Island, *Big Timber Refuge Habitat Rehabilitation and Enhancement, Upper Mississippi River System Environmental Management Program Definite Project Report (R-5) with Integrated Environmental Assessment*, July 1989.

USACE, Rock Island, *Cottonwood Island Habitat Rehabilitation and Enhancement, Upper Mississippi River System Environmental Management Program Definite Project Report (R-16F) with Integrated Environmental Assessment*, June 1996.

USACE, Rock Island, *Princeton Refuge Habitat Rehabilitation and Enhancement, Upper Mississippi River System Environmental Management Program Definite Project Report (R-10F) with Integrated Environmental Assessment*, February 1995.

USACE, Rock Island, *Potters Marsh Rehabilitation and Enhancement, Upper Mississippi River System Environmental Management Program Definite Project Report (R-9F) with Integrated Environmental Assessment*, April 1992.

USACE, Rock Island, *Operation and Maintenance Manual Big Timber Refuge Habitat Rehabilitation and Enhancement, Upper Mississippi River System Environmental Management Program, Pool 17, Mississippi River Miles 443-445, Louisa County, Iowa,* June 1994.

USACE, Rock Island, *Operation and Maintenance Manual Cottonwood Island Habitat Rehabilitation and Enhancement, Upper Mississippi River System Environmental Management Program, Pool 21, Mississippi River Miles 328.5-331, Lewis and Marion Counties, Missouri,* March 2001.

USACE, Rock Island, *Operation and Maintenance Manual Princeton Refuge Habitat Rehabilitation and Enhancement, Upper Mississippi River System Environmental Management Program, Pool 14, Mississippi River Miles 504.0-506.4R, Scott County, Iowa,* July 2002.

7.3.4. Case Studies

Big Timber Refuge. Ten 0.03-0.08 acre potholes,, 8 feet deep, constructed with explosive; used as cover for predators, not desirable habitat.

Cottonwood Island. Two 1-acre potholes, one ¾-acre pothole, and two ½-acre potholes were mechanically excavated. Areas used by local wildlife but not migrating waterfowl.

Potters Marsh. Nineteen potholes, ranging in size from 0.11 acre to 1.31 acres for a total of 8.3 acres, constructed with explosives and excavation. Used by local wildlife and migrating waterfowl.

Princeton Refuge. Strips of borrow material taken for berm construction with 10 foot staggers between strips; supposed to function as potholes. More thought in designing potholes could have led to better habitat value.

7.4. Mast Tree Planting

7.4.1. Design Methodology. The Corps employs talented foresters who are responsible for maintaining forested lands owned by the Corps. They have a vast knowledge of best management practices for tree plantings and should be consulted at every step of the planning process.

7.4.2. Lessons Learned

- Tree mortality along the Upper Mississippi River has been positively correlated with flood duration and amplitude. This mortality seems to be greatest in small trees. In fact, mortality of saplings was as high as 80% near St. Louis, Missouri, after flooding in 1993, with many areas experiencing 100% mortality of seedlings. In addition, numerous studies have shown that flood tolerance of trees is species specific. Thus, reforestation success at sites that have a high flood potential can be increased by planting taller seedlings or tree species that are more flood tolerant.

- It is important to quickly establish vegetation in the littoral zone of newly created islands in order to protect them from erosion. Black (Salix nigra) and sandbar willow (Salix exigua) cuttings have been successfully planted on EMP islands in the past and are planned for future projects. Cuttings are collected in the spring prior to leaf-out and are cut 20-25 inches long, as straight as possible, and range from 3/8 to 3/4 of an inch in diameter at the small end. They should be planted as soon after cutting as possible or stored properly. If planting will take place within a few days, the cuttings may be kept safely by placing the butt ends in water or by heeling-in in moist soil. Cover with wet burlap sacks to prevent exposure to sun or wind. If longer storage is needed (i.e. until after the start of the normal growing season), the cuttings should be placed in cold storage with temperature between 28 and 32 degrees F.

  The cuttings may be bundled together, stacked, and covered with moist burlap. Moisture should be maintained by lightly sprinkling with water as needed. Planting rods made of rod iron with a handle and step, or small power augers have been used successfully to plant cuttings quickly. If soil moisture is high, the cuttings may be pushed into the ground by hand. If rods or augers are used, the cuttings should be pushed to the bottom of the hole to prevent air voids. Approximately 5 inches of cutting should remain above ground and the top of the hole should be closed with a kick of the heel. Eastern cottonwood (Populus deltoides) cuttings can also be planted above the littoral zone on newly created islands using similar techniques. Other species that can be established easily with cuttings are dogwoods (Cornus sp.) and indigobush (Amorpha fruticosa).

- Willow and cottonwood seedlings often regenerate naturally and fairly quickly on sites at low elevation. In some cases, it may be possible to rely on natural regeneration, in combination with a protective cover of grass, to meet vegetation establishment goals. These sites may eventually succeed into floodplain forest. However, the potential exists for invasive species such as reed canary grass (Phalaris arundinacea) to form dense monocultures. Actively planting islands is the preferred option in most cases.

- Consideration should be given to using large-sized (3 ft. or greater) tree seedlings for reforestation of bottomland hardwoods. Although the cost for planting materials and labor for planting are higher, survival and growth are generally better. In addition, the larger seedling stock can be planted at a wider spacing, saving on overall costs. Most private nurseries and some state nurseries can supply large seedlings. A fairly recent innovation in tree seedling production is the RPM tree, or root production method. Local tree seed can be collected in the vicinity of the project site 18 months prior to construction, then delivered to the nursery where the seed is grown into RPM seedlings. Average seedling height when ready for transplant is 4-7 feet. Survival and growth characteristics of these seedlings have been excellent, mainly because of the robust root systems that are produced in the RPM process. RPM seedlings can be available for either fall or spring planting.

- Tree plantings have been successfully established in both the spring (mid-April to mid-June in MVP) and fall (mid-Oct to mid-Nov in MVP). Seedling availability from nurseries is usually better in the spring.

- Tree plantings need weed control for a minimum of three years. Tree mats can provide this and are highly recommended at the time of planting. But depending on the height growth of surrounding grasses, even trees with mats may need weed control for several growing seasons after they are established.

- Tree shelters also require regular maintenance. Floods and wind can tip the shelters over or cause them to lean. Other vegetation can grow up inside the tube and choke out the seedling. Use caution when cleaning out tree shelters during the summer and fall as they sometimes contain bee and wasp nests inside the tube.

- Tree shelters come in various heights. Four to five foot tubes are good if the potential for deer damage is severe. However, shorter tubes (2-3 foot) may be adequate for protection from other animal damage. Of course, the shorter tubes are cheaper and easier to install.

- At low elevations, tree shelters can collect significant amounts of sediment during flood events, sometimes causing seedling mortality.

- Avoid using tree shelters on plantings where prescribed fire is to be used within five years of project completion.

- If possible, avoid row planting of tree seedlings to make the site look more natural and improve aesthetics.

- Quality assurance is very important during contract planting operations to ensure seedling survival and success. Among the critical items to check for is how well the planting stock was protected during storage and handled during planting. The sensitive roots of seedlings must be kept cool, moist, and out of the wind and sun from the moment they are lifted out of the nursery bed until they are covered with soil in the transplant location.

- Quality assurance is also very important in verifying the source of planting materials. The general guideline is to acquire materials where the seed source is within 200 miles of the project location. Closer is better. The seed source should also be from a parent plant that actually germinated and is growing in a floodplain environment.

- Voles and other rodents can cause severe damage and mortality to tree plantings by girdling the lower stems and/or roots. Tree shelters, tree wrap, and rodent repellants are among the options that have been used to address this problem. However, tree shelters must be properly installed so as not to leave a gap at the base of the tree for rodents to enter.

7.4.3. References

USACE, Rock Island, *Brown's Lake Habitat Rehabilitation and Enhancement, Upper Mississippi River System Environmental Management Program Definite Project Report (R-5) with Integrated Environmental Assessment,* November 1987.

USACE, Rock Island, *Initial Post-Construction Performance Evaluation Report For Brown's Lake Habitat Rehabilitation and Enhancement Project,* February 1993.

USACE, Rock Island, *2003 Post-Construction Performance Evaluation Report For Brown's Lake Habitat Rehabilitation and Enhancement Project,* October 2003.

USACE, Rock Island, *Cottonwood Island Habitat Rehabilitation and Enhancement, Upper Mississippi River System Environmental Management Program Definite Project Report (R-5) with Integrated Environmental Assessment,* June 1996.

USACE, Rock Island, *3-Year (YR) Post-Construction Performance Evaluation Report For Cottonwood Island Habitat Rehabilitation and Enhancement Project,* June 2001.

USACE, Rock Island, *2002 Post-Construction Performance Evaluation Report For Cottonwood Island Habitat Rehabilitation and Enhancement Project,* April 2002.

USACE, Rock Island, *Long Island (previously Gardener Division) Habitat Rehabilitation and Enhancement, Upper Mississippi River System Environmental Management Program Definite Project Report (R-5) with Integrated Environmental Assessment*, Sep 2000.

USACE, Rock Island, *Post-Construction Performance Evaluation Report Memorandum for Record For , Long Island (previously Gardener Division) Habitat Rehabilitation and Enhancement Project,* June 2004.

Wlosinski, Joseph H. and Laurie B., *Predicting Flood Potential to Assist Reforestation for the Upper Mississippi River System.*

7.4.4. Case Studies

Brown's Lake. Pool 13, Upper Mississippi River Miles 544.0 - 546.0, Jackson County, Iowa. One feature of this project involved placement of dredged material into a terrestrial site to depths of 6 to 8 feet and re-planting with mast production trees. One of the project goals was to establish bottomland hardwood.

In May, 1990 a 150 foot wide strip immediately adjacent to the upstream dredge material containment levee was direct seeded with pin oak acorns. Approximately 25,000 acorns were dropped by helicopter onto this 150 foot wide strip. On May 20, 1991 a strip survey of this area was conducted by the COE. Strips three feet wide and fifteen feet apart were surveyed for pin oak seedlings. Based on this survey it is estimated that 1200 pin oak seedlings were growing on the site at this time. The pin oak seeding immediately adjacent to the upstream containment levee was somewhat successful. Approximately 5 percent of the acorns dropped produced seedlings after the first year.

These seedlings have since died from extended inundation in 1992 to 1993. This site was re-planted with mast producing hardwoods in June 1992. No planting of trees within the placement site was successful before this time due to consolidation and drainage problems. Future projects which consider dredged material placement sites for reforestation should include design of a drainage system for the placement site.

In addition to the objective of increasing bottomland hardwood diversity this project has the secondary objective of developing valuable data regarding the planting of mast production trees on dredged material deposits. Iowa State University has been contracted to plant the trees and monitor their survival while evaluating the following objectives:

- species suitability based on growth survival
- the use of nurse crop species on early growth survival of trees
- the use of different kinds of seedling stock types on early growth and survival of trees
- the use of applications of sewage sludge and fertilizer on early growth and survival of trees

Only species native to the region were selected for planting. Species known for their value as wildlife food were given priority for planting. Two kinds of plots have been established on the study site. The first consists of smaller 16-tree plots that will test the suitability of 13 different mast producing species for planting on this site. The second kind of plot is large and in total covers most of the area. These plots were planted with 3 mast-producing species, Black Walnut or Shellbark Hickory, Red Oak and Bur Oak. Nested within these plots are subplots to test the use of sludge as an organic amendment, the use of nurse crops to control competition, and the use of fertilizer to increase growth rates.

The technique of aerial pin oak seeding immediately adjacent to the upstream containment levee was somewhat successful. While creation of the dredged material containment area did succeed in raising the elevation of the placement site, much of this area remains too poorly drained to be suitable for regeneration of mast-producing tree species. Mast trees planted as part of the Iowa State University revegetation study are growing on sites in the containment area that are relatively higher in elevation and better drained than the surrounding ground. This mast tree component currently occupies only a small percentage of the replanted area. Persistent poor drainage in much of the containment area limits the likelihood that further active mast tree revegetation efforts would be successful. Natural revegetation of the area by wet-soil adapted tree species such as willow and cottonwood appears to be underway. Over time, further consolidation of the dredged material may provide more favorable conditions for mast tree production. Although some mortality of the mast trees currently established on the site will continue to occur, those that survive to maturity could provide a future seed source for natural mast tree regeneration in the long term.

Long Island Division (Gardener Division). Pool 21, Upper Mississippi River Miles 332.5 - 340.2, Adams County, Missouri. Two of the project objectives were to 1) reduce forest fragmentation and 2) increase bottomland hardwood diversity. The project area also has one of the last high quality stands of bottomland forest in the middle reaches of the Upper Mississippi River. In order to meet the objectives it was decided to plant 67 acres of mast-producing trees on the dredged material placement site located on Long Island's eastern agricultural field.

A meeting was held on November 12, 2003 at the project's construction site on Long Island to inspect the mast tree plantings and assess the success and condition of the previous two plantings. The team had concerns about tree survival due to the abundant weed growth. The tree plantings appeared to have good survivability, but were stressed by the amount and height of weeds around them. The tall weeds have the potential to lay over the tree plantings stunting their growth or killing them. It was decided to use herbicide and seeding options to aid in the tree's survival. It was suggested that in future mast tree plantings, that berms be seeded as well as the rows between the berms.

During a later inspection, District foresters felt that the flooding helped manage the weeds around the mast trees and will give the trees a better survival rate.

Cottonwood Island. Pool 21, Mississippi River Miles 328.5 through 331.0, Lewis and Marion Counties, Missouri. One of the project objectives was to increase bottomland hardwood diversity and quality. The features used to obtain this objective were the planting and attempted establishment of trees in existing management/crop areas and on elevated ridges.

Several sites were been selected for planting throughout the project area. Restoration of a mast-producing tree component to these areas would provide wildlife with an additional winter food source for a period of up to 100 years. Pin oak, swamp white oak, bur oak, pecan, and sycamore would be planted on a 30-foot spacing. Species would be intermixed at each site to avoid solid blocks of individual species.

Large stock seedlings greater than 4 feet in height would be planted to introduce a component of mast-producing trees to the project area. The tree plantings would be spaced and distributed to allow for a natural appearance. This enrichment planting technique differs from a plantation tree culture, where the objective would be to make mast-producing trees the dominant species. Instead, enrichment plantings are designed to introduce a component of mast-producing trees to create a mixed forest stand.

Pin Oak, Sycamore, Bur Oak, Northern Pecan, and Swamp White Oak were planted at designated locations at each planting site. Ground disturbance for mast tree planting occurring on previously harvested forest management areas consisted of cutting and removing all woody vegetation within 6 feet of the center point for the planted tree and then excavating a planting hole 2 feet in depth and 3 feet in diameter. Tree planting operations within the agricultural field involved disking to a depth of 4 inches, this was followed by excavation of planting holes. The forest management areas maintained a natural appearance throughout the establishment process, as only the vegetation directly surrounding the seedling was controlled. On the dredged placement site, soil disturbance for tree planting was limited to the newly placed material only.

A cover crop of red top grass and annual grains was to be established in the tree planting sites to help control unwanted weed species. Herbicides were used to control any competing vegetation. After a 3-year establishment period, the surrounding ground in all planting areas were allowed to assume natural regrowth.

Better than 95% of the Mast trees planted in the Agricultural field have survived with most thriving. Some of the Sycamore trees planted in this area are over 20 feet tall with the trunks of some of the Oak trees over 8 inches in diameter. It is not known why the trees in this area are doing so much better than the others areas. It was noted that the trees were container grown when planted and the mats placed around the trees at the time of planting are present for nearly every tree in the Agricultural field. The additional size of the plantings and the removal of competition for nutrients and other benefits gained by the securely placed mats seem to have been of great benefit.

The following reforestation recommendations and guidelines were provided by Kurt Brownell and Randy Urich, Foresters, St. Paul District

- Mast is an important diet component of many wildlife species and the most important mast-producing tree found within the bottomlands of the upper Mississippi River in the St. Paul District is swamp white oak (Quercus bicolor). The La Crescent Natural Resource Project Office surveyed a number of locations in 2003 and determined that the average minimum elevation above mean pool elevation where swamp white oak occurs is 2.17 feet, and for black oak (Quercus velutina) it is 3.01 feet. While this conclusion is based on data from only three pools, it at least establishes rough guidelines.

- Consider flood frequency and current velocity before using tree shelters on low elevation islands. Floodwaters can tip over or remove shelters, resulting in dead, deformed or damaged trees. Tree mats may not hold up on low areas either, but are more likely to stay in place than shelters. The weed control that mats provide may still be worth the risk of using them on low areas.

- Fine sediments with a high percentage of clay may be more difficult to establish trees on. This is especially true if there is significant compaction from heavy equipment during construction. One potential solution is the use of power augers during tree planting to loosen the soil in the planting hole.

- An excellent set of modeling tools are available to assist in selecting sites, trees species, and tree sizes for successful reforestation. These flood potential models for the Upper Mississippi and lower Illinois Rivers are available from USGS at http://www.umesc.usgs.gov/reports_publications/psrs/psr_2001__01.html.

7.5. Native Grass Planting

Native prairie grasses provide habitat, cover, and food sources for indigenous wildlife. Much of the native grasslands that once existed throughout the Midwest have been lost due to agricultural conversion, urbanization of open spaces, fire suppression, and changes in nutrient content of surface water runoff. Reestablishing native grass stands restores this lost habitat structure.

The Anfang and Wege Report (2000) provides a large amount of information on the establishment of vegetation on islands and dredge material placement sites. The establishment of vegetation on HREP projects was successful and helped reduce site erosion, improved aesthetic appearance, and provided valuable wildlife habitat.

7.5.1. Design Methodology . A mixture of native prairie grasses including switchgrass, Indiangrass, little bluestem and Eastern gamma-grass is recommended. A mixture has proven to support more wildlife than a solid stand of any one grass. Some individuals believe that it is best to acquire seed from a site that is within 100 miles of the restoration site in order to preserve the genetic integrity of local plant populations, (*Prairie Establishment and Landscaping).*

Preparation of the seedbed is one of the most important steps in a prairie restoration. Proper restoration will reduce weeds, facilitate planting, and provide a suitable bed for seed germination. A good seedbed will increase the success of a prairie planting while a poor seedbed will promote failure.

If planning a spring planting, begin seedbed preparation in the fall prior to planting the following spring. Preparation of the site in the fall will damage root systems of perennial weeds and expose them to freezing temperatures and the dehydrating action of the winter winds. In the following spring, the ground should be worked at a shallow depth at least twice to break up clods and eliminate annual weeds. Deep cultivation exposes more weed seed, eliminates the firm underbase which is necessary for successful prairie establishment and may cause prairie plant seeds to be planted several inches deep, making it impossible for the seedling to reach the surface.

The ideal spring planting date varies with location and climate but generally includes a two-month period from April 15 to June 15, with the earliest planting being made in the southern reaches. Plantings made after the middle of June run the risk of encountering hot, dry weather which will reduce seed germination and seedling survival. It is also possible to plant during the late fall, thus allowing seeds to stratify naturally in the soil. If planting in the fall, be sure to plant late enough so that seeds germinate the following spring. The freezing temperatures could kill the seedlings if planted too early, (*Prairie Establishment and Landscaping).*

It is important for the designer to remember that increased plantings are less likely to work if the site management does not alter. Fire is a vital part of the genesis of native grass prairies. Though fire suppression is a natural instinct, it should be discouraged for the healthy development of grasslands. Fires eliminate the accumulation of dead leaves and stems of prairie plants and retard the encroachment of trees and shrubs. Trees and shrubs have vulnerable living tissue above ground and, therefore, are subject to the intense heat of fire. In contrast, most prairie plants are deep rooted perennials that go dormant in the autumn and winter months leaving only dead, extremely flammable tops exposed to fire. These grasses do not need to be reseeded after fire if have already been established, (*Prairie Establishment and Landscaping)*.

The seeding rate may vary according to your objectives for the planting. If you want a pure stand of grass, a seeding rate of 8 to 10 pounds per acre should be sufficient for this purpose. If you desire a mixed stand with numerous prairie flowers, reduce the amount of grass to 2 to 4 pounds per acre, particularly the larger grasses such as Indian grass and big bluestem. Increase the amount of wildflower seed until the mixture is 60% grass and 40% wildflowers by weight (Rock 1977). It is also possible to reduce the volume of grass by utilizing a process known as “debearding”. In this procedure, the seed of big bluestem, Indian grass, or little bluestem is processed in a machine which removes the awns or "beards". The removal permits the seeds to pass through seeding devices more easily. If the seed has been debearded, reduce the amount listed by one-fourth.

When planted together, the total weight of the grasses should not total more than 6 pounds. This is a recommendation. The ratio of grass to forb seed will often be a matter of personal preference, seed availability, and cost.

Additionally, efforts should be made to reduce the exposure of the grasslands to nutrient-rich runoff. Certain invasive species, for example reed canary grass, are highly nutrient tolerant. The introduction of nutrient-rich runoff favors these invasive species and may reduce the likelihood of success in native grass plantings.

When dealing with large stands of undesirable or invasive species, herbicides may be needed to kill or weaken the existing plants. This allows the more desirable native species to gain a stronghold in the area. It is recommended that a habitat friendly herbicide, such as Aqua Master® is utilized in this application, as runoff from the upland areas will wind up in wetlands, streams, and rivers prior to chemical degradation, (*Better Wetlands*).

The seed of prairie plants can be planted by a variety of methods, including specially made drills, rotary spreaders, or hydraulic mulchers. Any large scale planting which does not drill the seed into the ground will require the use of a harrow to "set" the seed. If the conditions are suitable, and the seed viable, it should germinate within two or three weeks.

The use of no till prairie seed drill has increased dramatically. Using no till planters reduces the costs, saves time, and prevents disruption of the soil that could be experienced with traditional methods of planting.

During the first year of after planting, do not expect to see much growth from the prairie plants. It is during the first year of growth that most prairie plants establish their root systems. After two or three years, if survival is good, the prairie plants will be well established. Both Betz (1986) and Schramm (1990) describe the importance of establishing the "prairie matrix", a group of easily established prairie plants that represents the initial stage of succession that eventually leads to the development of a planting much like a native prairie remnant.

7.5.2. Lessons Learned

- A higher percentage of seeded species were dominant on sites with more than 1 foot of fine material (68%) than on sites with less fine material (56%).

- Fine material sites with more than 35% silt/clay had a higher average percent cover than sites with lesser amounts. At least 15% fines in the topsoil is sufficient to establish vegetation, however.

- Prescribed burns should follow herbicide treatments. After grasslands are treated with herbicides, large amounts of dead biomass exist on the ground. It is difficult for new seeds to germinate under this biomass, and seeds that are broadcast may not reach the ground surface at all. A prescribed burn consumes this excess biomass, preparing the soil for future new growth, (*Prairie Establishment and Landscaping*).

- Fine material increased the density of vegetation (both planted and naturally occurring). Six inches of fine material should be the minimum used for capping. The percent cover is highest on vegetation sites that were capped with more than 1 foot of fine material. A thicker cap of fine material with a higher percentage of fines may encourage a dense growth of woody and herbaceous cover.

- The fine material should contain sufficient coarse material to allow for aeration and water infiltration. This should be included in the specifications for the project.

- Switchgrass was recorded as the most common species on vegetation sites twice as often as any other species. At some sites the high density of switchgrass may have reduced the abundance of other vegetation by shading or other means.

- It may take several growing seasons (three to six) before vegetation reaches a desired/maximum density.

- The monitoring effort could not explain why some vegetation sites quickly convert from grasses to dense herbaceous and woody vegetation. Possible explanations include the proximity of some sites to other woody vegetation, whether or not the site was seeded to grass in the first place, the elevation of the site (higher sites favoring grasses), and the depth and consistency of fine sediments used as topsoil.

- 8-inches of fine sediment is too much for disking with standard farm equipment.

The following reforestation and revegetation recommendations and guidelines were provided by Kurt Brownell and Randy Urich, Foresters, St. Paul District

Soils

- Coarse, sandy dredged material is a poor medium for plant growth. It is important to incorporate some form of organic material with the sand to provide a suitable environment for seed germination, plant establishment and survival. To date, UMR revegetation projects have generally utilized fine sediments dredged from backwaters for topsoil. This has worked well. Sewage sludge and compost are other options being explored on a limited basis.

- Fine material placement techniques that have worked successfully include: mechanical dredging in backwaters with placement using front-end loaders; hydraulic dredging in backwaters using containment cells for placement on the site and follow-up spreading and incorporation with heavy equipment; use of an irrigation sprayer to apply fine material dredged from a backwater using a small hydraulic dredge; and use of dump trucks to deliver topsoil where the project site is accessible by land.
- Ideally, fine material and soil amendments should be incorporated into the base material. Six inches of soil depth is often suitable for planting grass and forbs, with dry prairie species possibly requiring a bit less.

- To help promote long-term survival and health of vegetation plantings, project sponsors should be encouraged to monitor soil nutrient levels at reasonable intervals after the project is completed. Color and condition of foliage plus plant size may be used as an initial indicator. If a problem is suspected, a soil test will confirm the nutrient levels and can be arranged through local extension offices. Follow-up action may include application of fertilizer.

- Soil erosion can be very effectively controlled using vegetation. However, soil-holding capabilities vary between plant type and species. It is important to consult a vegetation specialist during the planning and design phase to help with plant selection.

Elevation

- Even within the floodplain, the flood tolerance of different plant species varies considerably. Elevation differences of six inches or less can determine whether a site will support certain types of plants. Therefore, it is very important to match plant species to elevations. A good general reference is Whitlow, T. H., and Harris, R. W. (1979). "Flood tolerance in Plants: A State-of-the-Art Review," Technical Report E-79-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS., NTIS No. AD A075 938.

- Post-construction flooding on low elevation islands usually results in establishment of new plant species from seed that is washed onto the site. Sometimes this new vegetation can significantly change the original composition and density of plants, and often includes undesirable species, such as vetch, purple loosestrife, reed canary grass and others. Therefore, it is recommended that simple, relatively inexpensive planting mix be used on these lower areas.

- Islands have the potential to support diverse stands of vegetation that can then provide benefits such as wildlife habitat, visual barriers, and protection from wind. Vegetation types include bottomland forest, grassland, and shrubby woody vegetation. Designing islands with diverse topographic relief provides managers with a greater number of vegetative options

Grass and Forbs

- Recommend using a diverse mix of native grass and forbs to ensure good overall survival. Wildflowers can enhance the appearance of the site.

- The Spring Lake EMP project delivery team designed two grassland seed mixes in 2004 for use on islands as shown in tables 7.1 and 7.2. For sections of islands where vegetative management will be minimal, the abbreviated prairie mix should provide a relatively quick cover of native species. On higher sections (4 feet above average pool), the diverse prairie mix is recommended. Planners should be advised that active management is required to maintain grassland on the river, to include mowing during establishment of the stand and periodic controlled burns later to control invasive species and woody vegetation. In addition to providing habitat benefits, native prairie grasses form deep, dense root systems that will ultimately provide more protection to the islands.

- On projects where mulch is utilized, planners should consider weed-free certified mulch. The Minnesota Department of Transportation has such a program and vendors are listed on their website. By using this mulch, the risk of infesting your island with an invasive plant species is much reduced.

Table 7.1. Abbreviated Prairie Mix

Common name	**Scientific name**	**Seeding rate (ounces per acre)**
Virginia wild rye	*Elymus virginicus*	48
Wild canada rye	*Elymus Canadensis*	48
Switchgrass	*Panicum virgatum*	32
Indiangrass	*Sorghastrum nutans*	16
Prairie cordgrass	*Spartina pectinata*	3
Black-eyed Susan	*Rudbeckia hirta*	2

Table 7.2. Diverse Prairie Mix

Common name	**Scientific name**	**Seeding rate (ounces per acre) PLS**
Big bluestem	*Andropogon gerardii*	25.5
Little bluestem	*Andropogon scoparius*	25.5
Sideoats grama	*Bouteloua curtipendula*	25.5
Rough dropseed	*Sporobolus compositus*	1
Virginia wild rye	*Elymus virginicus*	25.5
Wild canada rye	*Elymus canadensis*	25.5
Switchgrass	*Panicum virgatum*	4
Indiangrass	*Sorghastrum nutans*	25.5
Prairie cordgrass	*Spartina pectinata*	2
Black-eyed susan	*Rudbeckia hirta*	3
Evening primrose	*Oenthera biennis*	2
Purple prairie clover	*Dalea purpurea*	3
Brown-eyed susan	*Rudbeckia triloba*	2
Yellow coneflower	*Ratibida pinnata*	2
Bergamot	*Monarda fistulosa*	1
Blue vervain	*Verbena hastate*	1.5
Hoary vervain	*Verbena stricta*	1.5
Sky blue aster	*Aster oolentangiensis*	0.5
Frost aster	*Aster pilosus*	0.5
Showy sunflower	*Helianthus laetiflorus*	0.5

7.5.3. References

Illinois DNR Division of Natural Heritage, *Prairie Establishment and Landscaping, Natural Heritage Technical Publication #2*, 1997.

Anfang, R.A., and G. Wege, 2000. *Summary of Vegetation Changes on Dredged Material and Environmental Management Program Sites in the St. Paul District*, Appendix B, Habitat Parameter 4, Terrestrial Vegetation, Corps of Engineers.

7.5.4. Case Studies

Potters Marsh. One of the project features was to develop grassland on a CPS (confined placement site), with the objective of enhancing habitat for migratory birds by increasing feeding or resting areas by increasing suitability. Seven acres were designed for this feature.

The grassland area was constructed after initial settlement of dredged material. The area was seeded with selected grasses. This grassland area helped compensate for any lost vegetation due to the CPS construction and further enhanced the habitat values on the site. This grassland provides habitat for dabbling ducks as well as non-game species like the dickcissel and the indigo bunting. These improvements would provide an enhanced aesthetic environment for recreationists hunting or fishing within the complex boundaries.

The Refuge Manager reported that during the spring of 1997 several pairs of Canadian geese had nested in the interior of the CPS and mallards had nested on the associated berm and grassland areas. Small numbers of sandhill cranes visit the Savanna District each year. During 1995, a sandhill crane nest located near the containment site successfully hatched two young. This was the first documented sandhill crane nest in northwestern Illinois since 1872. Refuge staff observed nesting activity by sandhill cranes on or around the CPS grassland and berm in the spring of 1997, although actual nests or hatching success were not confirmed.

A third site visit to the CPS by Corps staff on October 2, 1997, showed cover crop rye grasses were still dominant on the berm and grassland. This third inspection revealed an increased presence of warm season grasses and forbs. Several species encountered, such as little bluestem, sideoats grama, and blue grama, were included in the seed mixture specified for the CPS. Other species, such as New England aster, Indian grass, and big bluestem, were not included in seeding specifications, but could either be natural components of the seed bank in the area or incidental inclusions in the seed mixtures applied after construction of the CPS.

During the October 2, 1997, site visit, Corps staff encountered a plant specimen tentatively identified in the field as the federally listed threatened species decurrent false aster (Boltonia decurrens). This identification was confirmed the following day by the endangered species coordinator at the Rock Island Field Office of the USFWS. The known range for this species in Illinois is limited to floodplains of the Illinois River and of the Upper Mississippi River downstream of the confluence with the Illinois. This species is not recorded as occurring in Carroll or Whiteside Counties, and the reason for its presence on the CPS feature at Potters Marsh is not known. There is a possibility that seeds of this species may have been accidentally transported to the site in seeding mixtures or through some other construction-related activity.

The initial vegetation response and observed waterfowl use of the area since construction indicates a positive response to the HREP and suggests that the project is providing benefits to migratory bird species. Establishment of a plant community dominated by warm season native grasses and forbs typically requires at least 3 to 4 years to fully develop, with periodic maintenance activity such as controlled burning to control less desirable vegetation (e.g., cottonwood seedlings). Continued monitoring of vegetation changes and migratory bird use within and around the CPS will help to determine the long-term performance of this feature.

On April 1, 1998, USFWS refuge staff conducted a maintenance bum of the berm and grassland areas of the CPS. Site visits conducted by Corps staff on May 22 and July 15, 1998, revealed an increased dominance of warm season grasses and forbs, as well as an increase in the number of species present. These initial observations suggest that the grassland community responded well to the initial maintenance bum.

Burning should be applied to the grassland and containment berm annually or biennially when possible. Mowing may also be beneficial where encroachment is initiating or when burning is not practicable.

The managed marsh continues to be submerged year round in order to control the encroachment of willow and cottonwood trees by keeping the marsh too wet for the trees to thrive. The project has been operated in this manner since June 2000. The strategy of flooding the marshland has been somewhat successful in killing undesirable vegetation, but encroachment remains a problem and would most likely worsen if the managed marshland were operated as a moist soil unit (moist soil units are drawn down in the summer months). Encroachment continues to be worse in the grassland area where the land is higher and flooding is not possible. Grassland and forb species were especially threatened by the encroachment.

The grasslands planted met the project objective of enhancing wildlife habitat.

7.6. Wetland Species Planting

Floodplain wetlands provide important nursery grounds for fish and export organic matter and organisms back into the main channel (Junk et al. 1989, Sparks 1995, Welcomme 1992).

7.6.1. Design Methodology. Before restoring a wetland, the designer should consider their primary goals. For instance, water levels may be regulated differently for waterfowl benefits than for water quality improvement.

Wetlands designed for waterfowl should be managed so that at least 50 percent of the surface area is less than 18 inches deep. This will enable emergent vegetation such as cattails to become established and grow vigorously. The other half of the wetland can range from 2 to 6 feet deep, but 3 to 4 feet of water is all that is necessary to assure water for duck broods.

Where water quality improvement is the primary goal, water depths should be less than 3 feet with vegetation over 75 percent of the wetland.

Water control structures can be used to periodically drain water off wetlands to enhance plant germination and otherwise manage wetland plants. The control structure can also be used to increase water depths to create open water areas.

Slow drawdowns ultimately result in more food and habitat for waterfowl and shorebirds. The drawdowns must be timed carefully to avoid adversely affecting invertebrates and amphibians, however.

It is a good idea to seed the adjacent land to a restored wetland to forbs and native grasses such that at least an acre of grass is available for each wetland acre, (*Better Wetlands*).

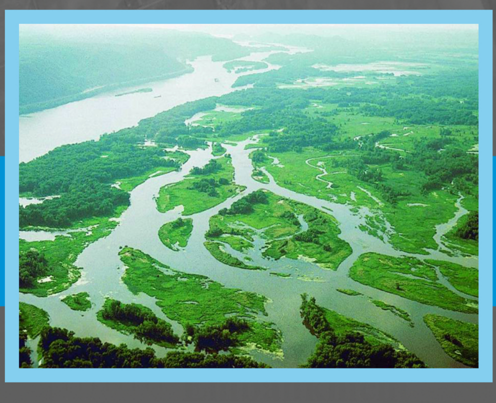
7.6.2. Lessons Learned. Studies have shown that it is not necessary to plant any wetland plants in the wetland itself. Simply returning water to the area results in aquatic vegetation developing within two years.

The aquatic plants that will likely grow include prairie cordgrass, arrowhead, cattails, sedges, marsh milkweed, water smartweed, and bulrushes, (*Better Wetlands*).

7.6.3. References

*Better Wetlands***,** October 1995, USDA NRCS, Iowa Association of Soil and Water Conservation District Commissioners, IDALS, Division of Soil Conservation

7.6.4. Case Studies. None listed.



TRIBUTARY RESTORATION

CHAPTER 8

UPPER MISSISSIPPI RIVER SYSTEM
ENVIRONMENTAL DESIGN HANDBOOK

CHAPTER 8

TRIBUTARY CHANNEL RESTORATION

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TRIBUTARY CHANNEL RESTORATION

8.1. Resource Problem

Large rivers, such as the Mississippi River and the Illinois River, are greatly influenced by their tributaries. Tributaries affect the hydrology, water quality, sediment characteristics, and physical configuration of the larger river that they enter.

In particular, sediment load from tributaries can have significant impacts to the ecology of the main stem river and backwater areas. "Sedimentation is among the most critical ecological problems of the Upper Mississippi River System (UMRS). The prediction that ecologically productive backwaters will fill and disappear in the next 50 to 100 years is alarming and clearly identifies sedimentation as a major concern of natural resource managers (USGS, Ecological Status and Trends, 1999)." Excessive suspended sediment can also be detrimental to aquatic organisms and plants.

Figure 8.1 showing a bed material (i.e. sand) budget for pools 1 through 10 of the UMRS illustrate the impacts of tributaries on coarse sediment transport. At each of the major sediment contributing tributaries in this reach (the Minnesota, Cannon, Chippewa, Zumbro, Root, Upper Iowa, and Wisconsin Rivers), there is a spike in the bed material on the UMR. The reaches that are labeled correspond to the geomorphic reaches identified in the Cumulative Effects Study (WEST Consultants, Inc., 2000). Reducing these sediment spikes could benefit not only the ecosystem, but also maintenance of the navigation channel.

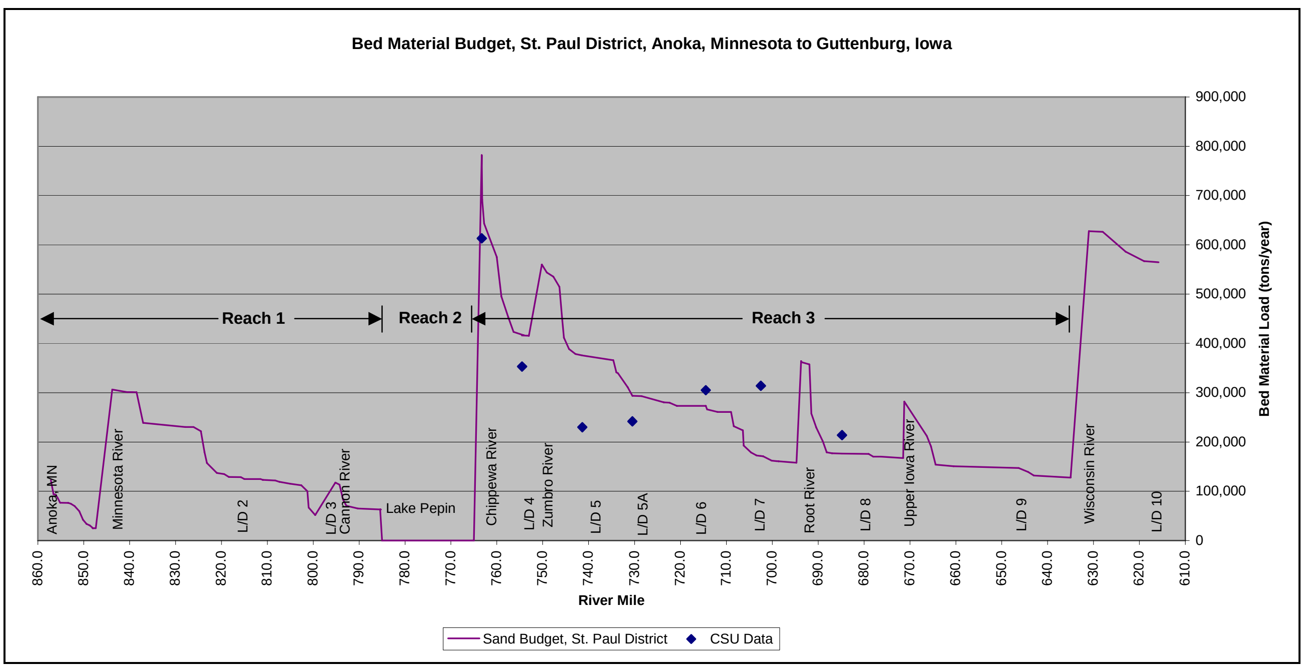

Figure 8.1. Bed Material Budget

Channelization of streams in the late 1800s and early 1900s involved straightening, deepening, and widening of existing channels as well as the headward extension of channel networks through the construction of numerous small artificial channels (Rhoads and Herricks, 1996). The channels were straightened to improve land drainage, lower flood stages, increase the acreage of farmable land, and reduce transit time for navigation. The channelization of tributary streams has contributed to the decline of suitable habitat and poor water quality. Channel modification or channelization activities are listed among the top 10 sources for non-point pollution impacts to rivers (U.S. Environmental Protection Agency, 1993). When a channel is straightened, the slope of the channel is increased, leading to higher velocities, increased erosion, and channel incision. This widespread erosion of sediment in the tributaries is carried to the main stem river.

A comparison of the bed material loads on the Black River which enters the UMRS in Pool 7 and the Upper Iowa River which enters in Pool 9 illustrate this concept.

Table 8.1. Comparison of Bed Load on Mississippi River Tributaries

	Tributary	
	Black River	**Upper Iowa River**
Drainage Area (square miles)	2,250	1,160
Bed material load entering the Mississippi Valley (tons per year)	220,000	115,000
Bed Material Load to Main Channel (tons per year)	0	115,000

The Black River, which was never significantly channelized, deposits its entire bed material load in a large delta that dominates the upper portion of pool 7. In the early 1990s, when the Corps and the Wisconsin DNR did a study of this area, three major and six minor distributary channels existed (Hendrickson, 1994). Sediment-laden Black River flow entered these distributary channels and eventually the entire bed material sediment load settled in some portion of the delta. A review of historic aerial photographs indicated that significant channel migration, with occasional avulsions, occurred on a decadal time scale. The resource managers involved with this study concluded that the dynamic conditions in the Black River delta resulted in excellent habitat and recommended that no efforts be pursued to manage this system.

The Upper Iowa River, on the other hand, was channelized in 1956, with dredged material placed in spoil banks on either side of the channel to further contain the river. Because of this, the entire bed material load of the Upper Iowa enters the main channel of the UMRS. This sediment affects habitat in downstream backwaters, and increases dredging in Pool 9. The following two photographs illustrate the difference between these two rivers.

Photograph 8.1. Black River

Photograph 8.2. Upper Iowa River

Tributaries not only contribute sediment to the system, but can also carry environmental contaminants. These contaminants include heavy metals, pesticides, synthetic organic compounds, and numerous other chemicals (USGS, Ecological Status and Trends, 1999).

Also, growth of deltas where tributary channels enter impounded areas of the navigation pools may result in a future river planform that resembles pre-impoundment conditions, with island- braided morphology, more tertiary channels, and fewer backwater areas than at present (USGS, Ecological Status and Trends, 1999).

Erosion in site-specific upland areas can have a significant effect on a project's floodplain and aquatic areas as the resultant sediment is deposited and accumulated in critical habitats. Yet, HREPs involving upland sediment control measures have not generally been pursued under the EMP. Upland sediment controls may be recommended for implementation if they are determined by an engineering analysis to be the most cost-effective way of preventing or reducing sedimentation in a project area that is within the UMRS floodplain (USACE, Report to Congress, 1997).

8.2. Tributary Channel Restoration

The topic of stream restoration is broad and encompasses many disciplines and design methodologies. Engineers, biologists, and geomorphologists may have very distinct ideas about what it means to "restore" a stream. An engineer may be concerned with flooding impacts or protecting infrastructure, a biologist may desire diverse habitat for fish and other aquatic organisms, and a geomorphologist may desire to return the stream to its "natural" planform and geometry. Product delivery teams should include all of these ideas while developing a stream restoration because streams are very complex and have multiple functions.

Restoration projects do not necessarily require returning a system to some predisturbance condition, as this is seldom feasible. The objective of a restoration project is then a partial recovery of the natural geomorphic, hydraulic, and ecological functions of the stream. It follows then that the design team requires expertise in the fields of geomorphology, hydraulics, and ecology (USACE, Hydraulic Design of Stream Restoration Projects, 2001).

Tributary restoration is a relatively new technique on the UMRS. Both the EMP and NESP programs offer the potential to consider tributary restoration, however, this will probably be limited to restoration of tributary channels where the tributary enters the Mississippi River Valley. While this may appear to be a limited approach, it could be very effective, as illustrated in the Black River and the Upper Iowa River example above. The Section 519 Program has been granted authority to construct projects in the Illinois River Basin, including tributaries. The Section 206 program may also provide the opportunity to construct stream restoration projects.

8.2.1. Design Methodology. The first step in a stream restoration project, as with any engineering project, is to clearly define project objectives in cooperation with stakeholders. In establishing objectives for a stream restoration project, it is advisable to assess at least the six following issues:

1. The existing condition of the stream and watershed.
2. The scale and severity of the resource loss or degradation due to stream instability.

3. Causal factors and controls that have resulted in the current stream condition. In this context it is useful to establish whether current instability in the channel is being driven by the current flow regime or is a product of past conditions.
4. The condition into which the channel is likely to evolve without a project. This often involves a strong reliance on geomorphic prediction coupled with engineering judgment.
5. The physical constraints on possible restoration measures such as water quality, available right-of-way or construction area, as well as budget constraints.
6. The range of alternative solutions that is both feasible and acceptable to the stakeholders (USACE, Hydraulic Design of Stream Restoration Projects, 2001).

In general, the engineering means to achieve the objective of stream restoration can be divided into three general categories based on the focus of the proposed solution: (A) hydrologic work, (B) habitat work, and (C) hydraulic work. Hydrologic work can be accomplished through the use of stormwater ponds or through the modification of reservoir release schedules to modify the runoff regime as necessary to meet project objectives. Habitat includes the construction of structures or features on the bed, bank, and/or riparian area to modify the biologic function of the stream. This can include measures that provide in-stream cover, low-flow channels, scour holes, riparian plantings, and substrate modification. Hydraulic work includes a variety of techniques that center on measures that affect the geomorphic characteristics of the channel. They can include measures to provide the channel dimensions and geometries required to produce a stable or regime condition, local works essential to supply the morphological diversity necessary to support a wide range of habitats, and the structures needed to hold the channel in its new alignment by preventing bank erosion (USACE, Hydraulic Design of Stream Restoration Projects, 2001).

Some disturbances to stream channels are so severe that restoration within a desired time frame requires total reconstruction of a new channel. If watershed land use changes or other factors have caused changes in sediment yield or hydrology, restoration to a historic channel condition is not recommended. In such cases, a new channel design is needed (FISRWG, Stream Corridor Restoration, 1998). In the case of tributary stream channelization in the Midwest, the hydrology, sediment yield, and land use have most likely been significantly altered by agricultural practices, so a new channel design may be required. If a new channel is not feasible or practical, other methods such as grade control, bank protection, or providing additional habitat structure could be implemented to provide habitat or reduce stream degradation.

The following simplified methodology for the design of a new stream channel is adapted and condensed from Stream Corridor Restoration: Principles, Practices, and Processes by the Federal Interagency Stream Restoration Working Group. A more comprehensive manual for detailed design of stream restoration projects is: Hydraulic Design of Stream Restoration Projects (USACE, ERDC/CHL TR-01-28). Both of these references further define the terms and the process for stream channel design.

Step 1. Describe physical aspects of the watershed and characterize its hydrologic response. This step should be based on data collected during the planning phase.

Step 2. Considering reach and associated constraints, select a preliminary right-of-way for the restored stream channel corridor and compute the valley length and valley slope.

Step 3. Determine the approximate bed material size distribution for the new channel.

Step 4. Conduct a hydrologic and hydraulic analysis to select a design discharge or range of discharges. The bankfull discharge is used by many designers, corresponding to approximately a 1 to 3 year recurrence interval flow. A sediment rating curve must be developed to integrate with the flow duration curve to determine the effective discharge. Incised streams are especially difficult to determine the bankfull discharge.

Step 5. Predict stable planform type. Stable channel bed slope is influenced by a number of factors, including sediment load and bank resistance to erosion. For the first iteration, restoration designers may assume a channel planform similar to stable reference channels in similar watersheds or undisturbed areas in the same watershed. By collecting data for stable channels and their valleys in reference reaches, insight can be gained on what the stable configuration would be for the restoration area. A designer could use aerial photographs or other historic information to gather insight about the stream prior to development or straightening. Also, the Rosgen classification system (figures 8.2 and 8.3) can be used to predict what a stable planform would be for the valley type, or topography of the area. A training module for using the Rosgen classification system is located at: http://www.fgmorph.com. Papers published by Rosgen about the classification system and natural channel design are available at http://www.wildlandhydrology.com/html/references_.html.

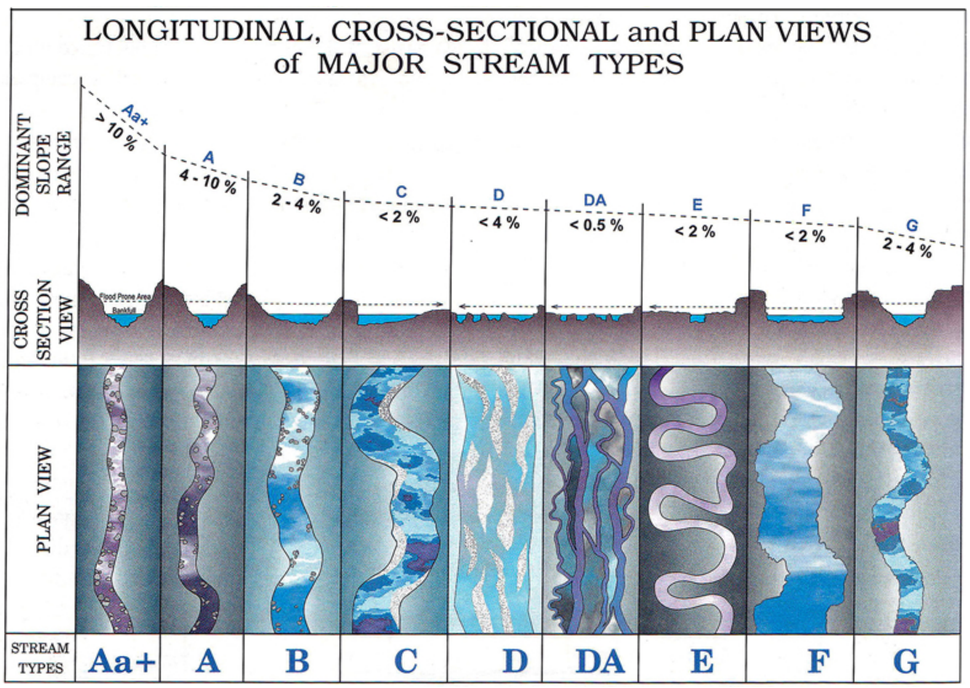

Figure 8.2. Rosgen Classification

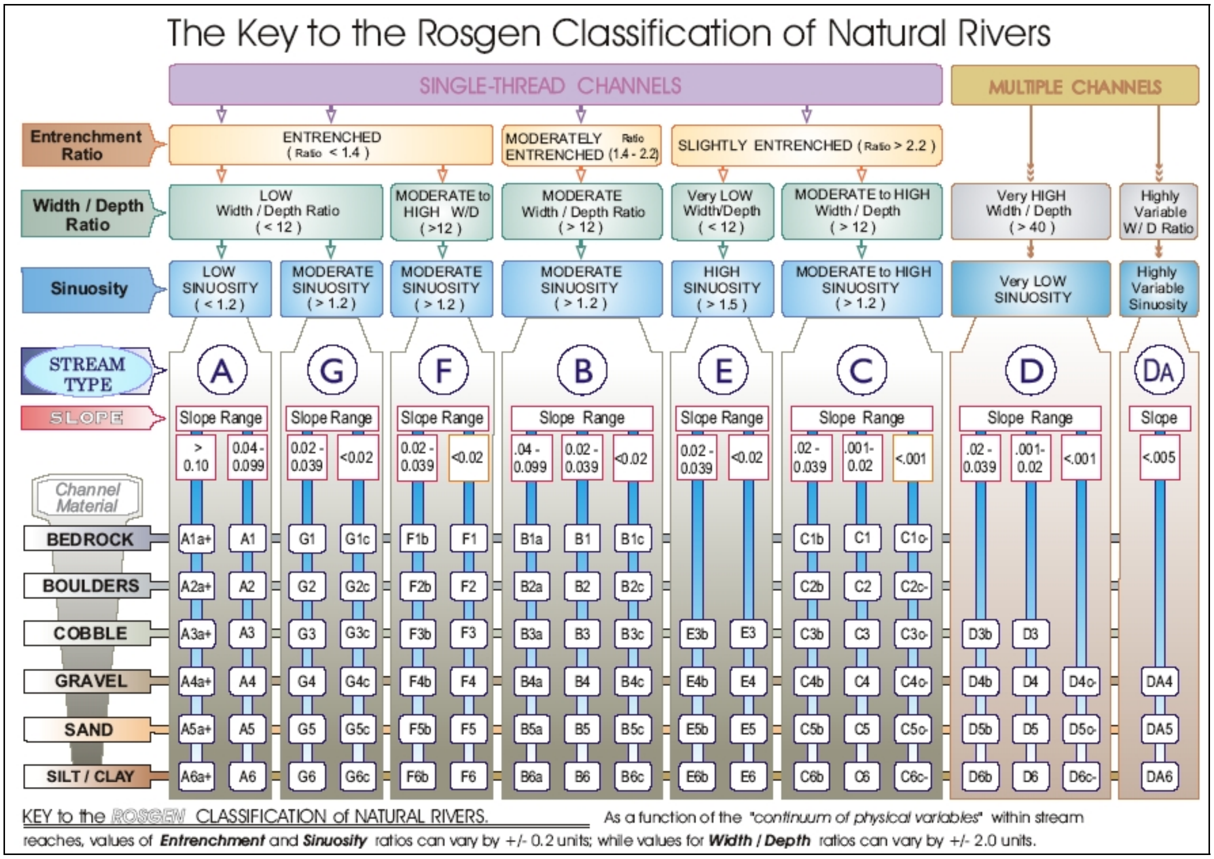

Figure 8.3. Rosgen Classification System

Once the stable planform type is established, the designer can proceed with the design. Three approaches are summarized in table 8.2 from the Stream Corridor Restoration Handbook.

> “There are three commonly applied approaches to natural channel design: analog, empirical, and analytical. Analog design replicates historic or adjacent channel characteristics and assumes equilibrium sediment and hydrologic conditions. Empirical design uses equations that relate various channel characteristics derived from regionalized or “universal” data sets, and also assumes equilibrium sediment and hydrologic conditions. Analytical design makes use of the continuity equation, roughness equations, hydraulic models, and a variety of sediment transport functions to derive equilibrium channel conditions, and thus is applicable to situations where historic or current channel conditions are not in equilibrium, or where applicable analogs or empirical equations are unavailable (Skidmore, Shields, Doyle, Miller, 2001).”

The analog approach includes the reference reach method, and the carbon copy approach. The reference reach method is used by Dave Rosgen, and described above. The reference reach method includes measurement and subsequent replication of a number of channel parameters, including width, depth, slope, bed material gradation, bankfull width, and sinuosity, among others. The carbon copy approach relies on replication of previous or historic channel characteristics (FISRWG, 1998). It is most commonly applied in the context of restoring meander planform in channels that have been straightened. Analog approaches are not valid if the sediment supply, hydrology, and boundary conditions are not similar for the analog and the design (Skidmore, Shields, Doyle, Miller, 2001).

"The empirical approach is referred to as the "Hydraulic Geometry Method" (FISRWG, 1998). Historic geomorphic studies of stable, natural channels resulted in "hydraulic geometry" formulas (Leopold and Maddock, 1953), which quantified attributes of channels in regime. These formulas generally relate dependant variables such as width, depth, or slope to independent variables such as discharge or bed material size, and are generated by a regression of large, regional data sets. Wharton (1995) states that the most significant problem in application of empirical relations is that they are only applicable over the range of conditions from which they were derived (Skidmore, Shields, Doyle, Miller, 2001)."

Analytical methods can be used to determine hydrologic and hydraulic design components, such as: water surface elevations, shear for bed and bank design, extent and duration of inundation, appropriate channel geometry, sizing bed material, and ensuring sediment continuity (Skidmore, Shields, Doyle, Miller, 2001). Programs used by the Corps of Engineers include HEC-6, SAM, HEC-RAS with the sediment option, and others.

Advantages and limitations of each approach should be carefully considered when applied to design of natural channels. The advantage of the analog and empirical approaches is the intuitive simplicity of replicating desired channel and habitat characteristics from stable systems. Analytical approaches are required when channel equilibrium is in question, and when no analog sites or empirical equations are applicable as a consequence of changing or differing hydrologic character and sediment inputs. The analytical approach often requires substantially more data, and more time than the other methods, and the reliability of the model is limited to the accuracy of the input variables and the applicability of the model to the design situation (Skidmore, Shields, Doyle, Miller, 2001).

Approach A		Approach B (Hey 1994)		Approach C (Fogg 1995)	
Task	**Tools**	**Task**	**Tools**	**Task**	**Tools**
Determine meander geometry and channel alignment[1].	Empirical formulas for meander wavelength, and adaptation of measurements from predisturbed conditions or nearly undisturbed reaches.	Determine bed material discharge to be carried by design channel at design discharge, compute bed material sediment concentration.	Analyze measured data or use appropriate sediment transport function[2] and hydraulic properties of reach upstream from design reach.	Compute mean flow, width, depth, and slope at design discharge.[4]	Regime or hydraulic geometry formulas with regional coefficients.
Compute sinuosity, channel length, and slope.	Channel length = sinuosity X valley length. Channel slope= valley slope/ sinuosity.	Compute mean flow, width, depth, and slope at design discharge.[4]	Regime or hydraulic geometry formulas with regional coefficients, or analytical methods (e.g. White, et.al., 1982, or Copeland, 1994)[3].	Compute or estimate flow resistance coefficient at design discharge.	Appropriate relationship between depth, bed sediment size, and resistance coefficient, modified based on expected sinuosity and bank/berm vegetation.
Compute mean flow width and depth at design discharge.[4]	Regime or hydraulic geometry formulas with regional coefficients, and resistance equations or analytical methods (e.g. tractive stress, Ikeda and Izumi, 1990, or Chang, 1988).	Compute sinuosity and channel length.	Sinuosity = valley slope/ channel slope. Channel length= sinuosity X valley length.	Compute mean channel slope and depth required to pass design discharge.	Uniform flow equation (e.g. Manning, Chezy) continuity equation, and design channel cross-sectional shape; numerical water surface profile models may be used instead of uniform flow equation.
Compute riffle spacing (if gravel bed), and add detail to design.	Empirical formulas, observation of similar streams, habitat criteria.	Determine meander geometry and channel alignment.	Lay out a piece of string scaled to channel length on a map (or equivalent procedure) such that meander arc lengths vary from 4 to 9 channel widths.	Compute velocity or boundary sheer stress at design discharge.	Allowable velocity or shear stress criteria based on channel boundary materials
Check channel stability and reiterate as needed.	Check stability.	Compute riffle spacing (if gravel bed), and add detail to design.	Empirical formulas, observation of similar streams, habitat criteria.	Compute sinuosity and channel length.	Sinuosity = valley slope/ channel slope. Channel length= sinuosity X valley length.
		Check channel stability and reiterate as needed.	Check stability.	Compute sinuosity and channel length.	Lay out a piece of string scaled to channel length on a map (or equivalent procedure) such that meander arc lengths vary from 4 to 9 channel widths.
				Check channel stability and reiterate as needed.	Check stability.

[1] Assumes meandering planform would be stable. Sinuosity and arc-length are known.

[2] Computation of sediment transport without calibration against measured data may give highly unreliable results for a specific channel (USACE, 1994, Kuhnle, et.al., 1989).

[3] The two methods listed assume a straight channel. Adjustments would be needed to allow for effects of bends.

[4] Mean flow width and depth at design discharge will give channel dimensions since design discharge is bankfull. In some situation channel may be increased to allow for freeboard. Regime and hydraulic geometry formulas should be examined to determine if they are mean width or top width.

Table 8.1 -- Three approaches to achieving final design. See text for first five common steps.
In Stream Corridor Restoration: Principles, Processes, and Practices, 10/98.
Interagency Stream Restoration Working Group (FISRWG)(15 Federal agencies of the US).

Table 8.2. Approaches to Natural Channel Design

8.2.2. Meander Design. Projects involving re-establishing meanders in a previously straightened reach, and other natural channel design projects, will require detailed design of meander geometry. "At this point, a word of caution is needed about re-establishing meanders in a previously straightened reach. While this is generally a commendable goal, and one that may be achievable in certain circumstances, it is usually not as straightforward as is often purported, particularly in large-scale projects, or where severe system instability exists or has existed in the past (Watson, Biedenharn, Scott, 1999).

Sinuosity is a commonly used parameter to describe the degree of meander activity in a stream. Sinuosity is defined as the ratio of the distance along the channel to the distance along the valley. Think of sinuosity as the ratio of the distance the fish swims to the distance the crow flies. A perfectly straight channel would have a sinuosity of 1.0, while a channel with a sinuosity of 3.0 or more would be characterized by tortuous meanders (Watson, Biedenharn, Scott, 1999). Figures 8.4 and 8.5 exhibit meander design criteria.

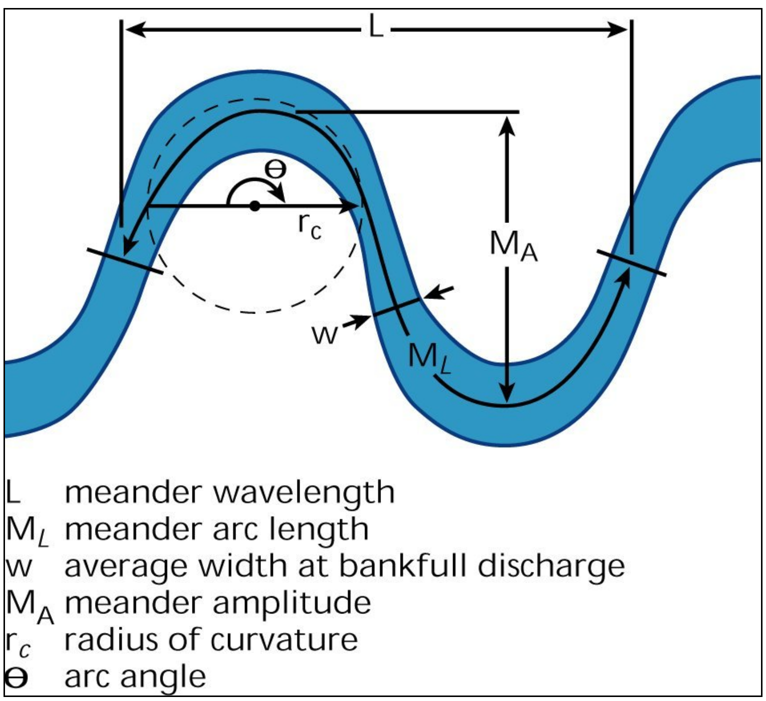

Figure 8.4. Typical Parameters used in Meander Design (FISWRG, 1998)

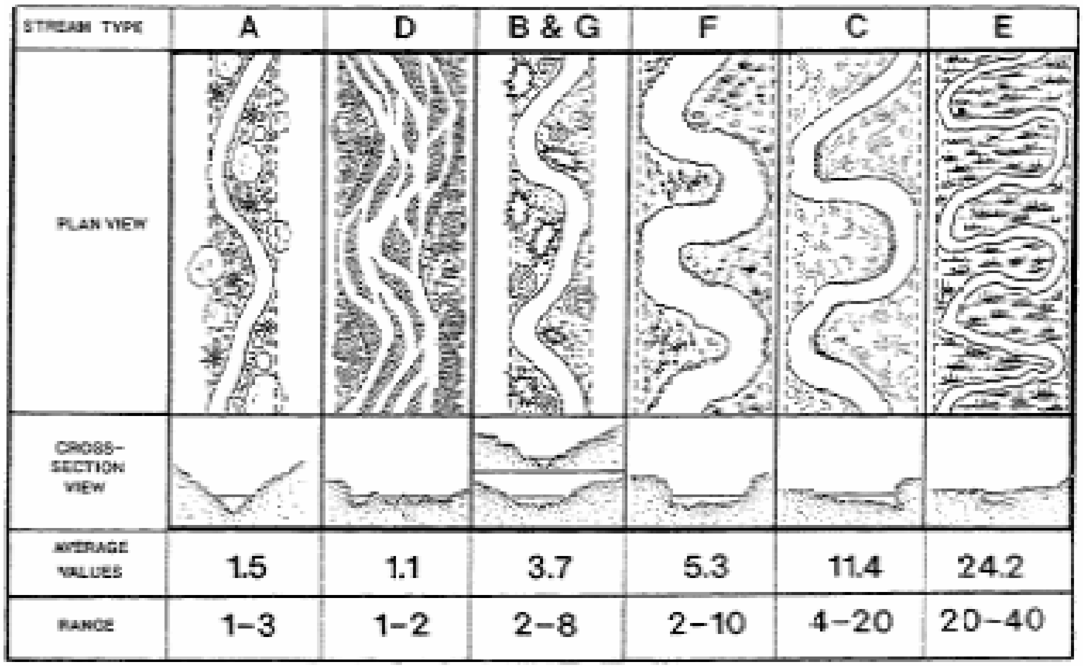

Figure 8.5. Meander Width Ratio (Belt width/Bankfull width) by Stream Type Categories (Rosgen, Catena, 1994)

There are five general approaches to meander design given in the Stream Corridor Restoration Handbook.

1. Replacement of meanders exactly as found before disturbance (carbon copy technique). This method is applicable if hydrology and bed materials are very similar or identical to pre-disturbance conditions.

2. Use of empirical relationships that allow computation of meander wavelength, L, and amplitude based on channel width or discharge.

3. Basin-wide analysis to determine fundamental wavelength, mean radius of curvature, and meander belt width in areas “reasonably free of geologic control.”

4. Use of undisturbed reaches as design models.

5. Slope first. Meanders designed by first selecting a mean channel slope based on hydraulic geometry formulas.

8.2.3. Stream Restoration Structures. There are several structures that have been proven to be effective in creating in-stream habitat, reducing stream bank erosion, and creating a stable stream. These structures include rock vanes, J-hooks, hard points, and dikes. These structures are discussed in more detail in other sections of this Design Handbook.

8.2.4. Lessons Learned. Numerous stream restoration projects have been constructed through other programs and by other agencies. A designer should attempt to gather information about other projects that have been completed in the area, and discuss the lessons learned and performance of the project. As tributary restoration projects are constructed through the Section 519, Section 206, NESP, and/or the EMP program, it is anticipated that the Corps will have additional experience and lessons learned from tributary restoration projects.

8.2.5. Case Study - Chippewa River Sediment Dynamics

Chippewa River Sediment Dynamics. The Chippewa River enters the Mississippi River at river mile 763.4 in pool 4 just downstream of Lake Pepin. It is the major contributor of bed material sediment (i.e. sand size sediments) to the Mississippi River in the St. Paul District. Roughly 1/3 of the total dredging done in the St. Paul District is from lower pool 4.

On the Lower Chippewa River, bed and bank erosion accounts for the majority of the sediment being transported, and nearly 90-percent of this was delivered to the Mississippi River. This is based on USGS measurements of bed load and suspended sediment at gaging stations on the Chippewa River during water years 1976-83 (Rose, 1992). D. B Simons and Associates Inc. (1998) used this data to develop the sediment budget shown in figure 8.6. The sediment transport relationship for the Chippewa River at Durand was used to estimate the sediment contribution from the Red Cedar River. Between Carryville and Durand, the total sediment load increased almost an order of magnitude from 123,000 tons per year to 1,073,000 tons year. Bed and bank erosion in the 26 river miles between Carryville and Durand accounted for 82-percent of the total sediment load at Durand with the Red Cedar River adding only about 7-percent of the total. At Pepin near the mouth of the Chippewa River, the total sediment load had dropped to 940,000 tons per year, due to 133,000 tons per year of floodplain deposition on the Chippewa River.

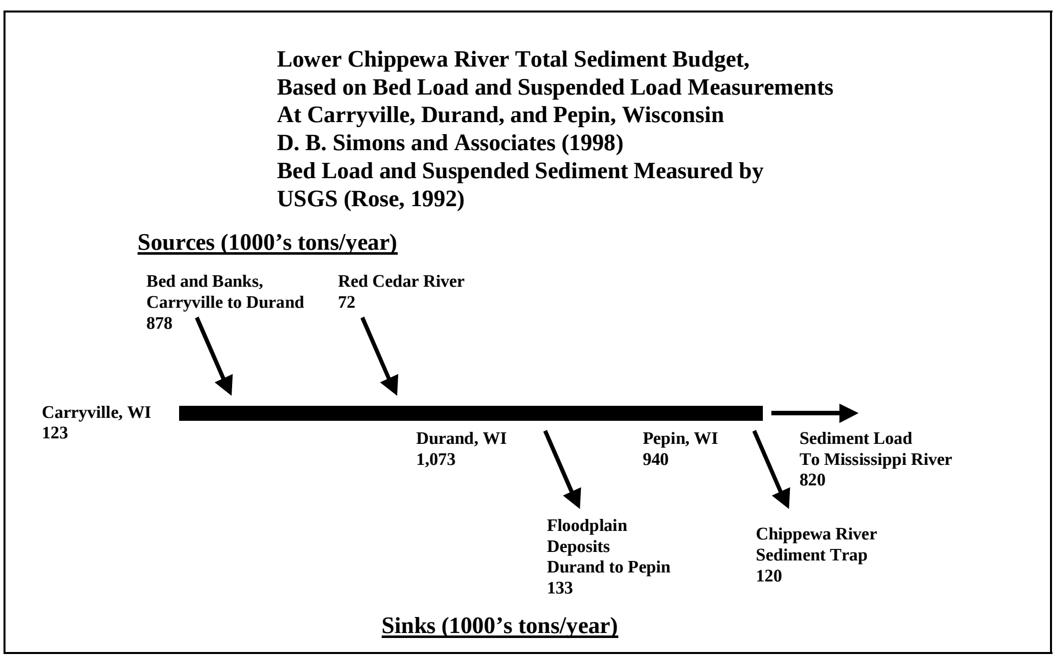

Figure 8.6. Lower Chippewa River Total Sediment Budget

Because the Chippewa River contributes so much sand to the Mississippi River, several projects have been done in this area to manage this sediment. These are summarized below.

Chippewa River Experimental Bank Stabilization Project, 1984. In the early 1980s, several techniques were used to stabilize the banks of the Chippewa River in the sediment producing reach from Carryville to Durand. One of the criteria for these techniques was that they had to be low cost (the cost of bank stabilization with riprap was already determined to be too expensive). Techniques involving geo-grids to reinforce the bank, vegetative stabilization, and others were tried. Later inspections indicated that none of these techniques was very successful and the project was not pursued further.

> **Lesson Learned.** Although, it is probably true that there aren't any cheap bank hardening techniques, at least not for a river as large as the Chippewa, the use of vanes should be considered for future use on tributaries like the Chippewa. Vanes, which redirect flow away from the bank were just being developed during the 1980s. They have been successfully used at dredged material placement sites on the UMRS , and are significantly cheaper than riprap.

Chippewa River Sediment Trap, 1984 to present. At the confluence of the Chippewa and Mississippi Rivers, a sediment trap has been maintained by the St. Paul District Corps of Engineers since 1984. Dredging of the trap averages 120,000 tons per year with the remaining 820,000 tons per year entering the Mississippi River.

> **Lessons Learned.** Because sediment traps tend to trap more sediment than the navigation channel, the overall dredging volumes in this reach of the river have increased since 1984. However, dredging of the trap resulted in significant decreases in dredging at the downstream Reads Landing and Crats Island dredge cuts (76-percent and 26-percent respectively). The reduction in dredging at Reads Landing has significance beyond the amount of material dredged. Prior to 1984, channel closures and emergency dredging were common occurrences at Reads Landing. This resulted in significant delays to the towing industry and environmental concerns regarding the emergency placement of the dredged material. This has been mostly eliminated through maintenance of the sediment trap.
>
> Although the Chippewa River sediment trap is maintained using O&M funds, it definitely reduces downstream sediment loads. Since sediment deposition is a major concern on the Mississippi River, the benefits the trap has in reducing the downstream sediment load and subsequent sediment transport to backwater areas is a positive impact. Sediment traps such as this could be considered at other tributaries.

Indian Slough Restoration Project, 1994. In 1994, over $500,000 was spent on the Indian Slough restoration project just downstream of the confluence of the Chippewa and Mississippi Rivers. The purpose of this project was to reduce the sediment load conveyed down Indian Slough into the Big Lake backwater and to reverse the effects of sediment deposition in Big Lake by dredging. This project successfully reduced the sediment load into Big Lake, however since Indian Slough is a major recreational route, a complete closure was not possible and sediment deposition continues to occur. Also, local anglers have reported the rock riffle pools (rock placed so as to change flow and create scour holes) and tree groins (log snags) at the Indian Slough, Wisconsin HREP are providing habitat for smallmouth bass and other game fish (Report to Congress, 2000).

8.2.6. References

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8.3. Sediment Basins

A sediment basin consists of an earth embankment or a combination ridge and channel generally constructed across the slope and minor watercourse to form a sediment trap and a water detention basin. Sediment traps can be used to reduce watercourse and gully erosion, trap sediment, reduce and manage onsite and downstream runoff, and improve downstream water quality (NRCS, Code 638, 2001).

While not expressly precluded under the EMP authorization, Corps policy has generally regarded such features (upland sediment control) as beyond its purview and as the responsibility of other agencies. Nevertheless, two HREPs with upland features (Swan Lake and Batchtown) have been advanced as a result of specific Congressional directives. In both instances, the upland sediment control features were the most cost-effective way of protecting habitat in the project area. These features include hillside retention ponds, terracing, and other measures to reduce sediment delivery to the specific project area, but do not extend to land conservation practices throughout the watershed (USACE, EMP Report to Congress, 1997). Figure 8.7 shows an example of a detention basin.

8.3.1. Design Methodology . The Natural Resources Conservation Service (NRCS) has expertise in designing sediment basins, developed through years of helping farmers and landowners to reduce erosion of their land. The NRCS has published two Conservation Practice Standard documents (Code 638 and 350) on the design of Sediment Basins that were used as a reference for this design methodology. The following guidelines should be considered during the design of a sediment basin; site specific requirements or project features could be modified based on the site and desired goals for the project.

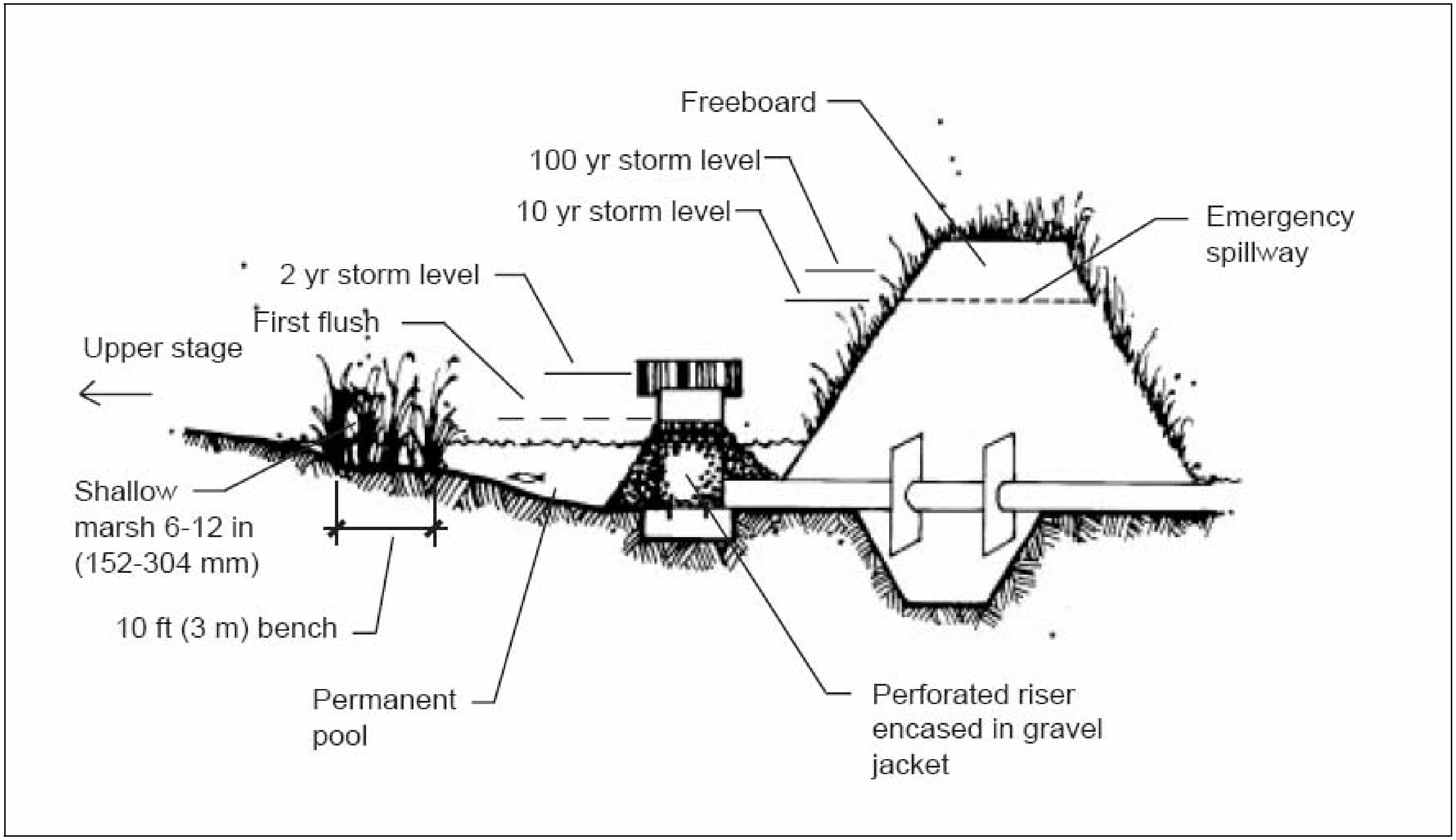

Figure 8.7. Detention Basin - Section View

8.3.1.1 Design Requirements. The following items should be included in the design of a sediment basin: Location and site map, soil type, drainage area and volume computations including sediment volume required, design cross sections, spacing, and outlet requirements.

8.2.1.2. Alignment. The embankment orientation and row direction shall be approximately perpendicular to the land slope to permit contouring.

8.3.1.3. Cross Section. The constructed elevation of the embankment shall be at least 5% greater than the design fill height to allow for settlement. The maximum design fill height shall be 15 feet. If the design fill height is less than 10 feet, the top width shall be 6 feet. If the fill height is between 10-15 feet, the top width shall be 8 feet. The slopes of the settled embankments shall be no less than 5H:1V, and no steeper than 2H:1V.

8.3.1.4. Capacity. The minimum basin design capacity shall be large enough to store the runoff from a 10-year frequency, 24-hour duration storm without overtopping. The basin shall also have the capacity to store 10 years of sediment accumulation unless provisions are made for periodic sediment removal from the basin to maintain the design capacity. The basin shall have the ends closed to the design elevation.

8.3.1.5. Outlets. Basins shall have underground outlets or soil infiltration outlets that meet the requirements of NRCS Code 600 and 620.

8.3.1.6. Vegetation. Slopes and disturbed areas shall be established to suitable erosion-resistant vegetation.

8.3.1.7. Requirements for Plans and Specifications. A location map, the profile along the centerline of the structure, cross section, outlet diameter, length, material, elevations, and seeding requirements should be included in the plans and specifications.

8.3.2. Lessons Learned. The following items are lessons learned from Swan Lake and Batchtown HREP projects.

- Baseline and Post Project Monitoring. Sediment control measures are currently not physically monitored after construction to measure effectiveness. Ideally, surveying the sedimentation trap impoundment prior to use and surveying periodically to measure the amount (tons) of sediment trapped would be desirable. The NRCS uses empirical formulas to determine the amount of sediment that will be prevented from entering a stream prior to construction based upon site conditions, but do not survey to verify their assumptions. The project sponsor (USFWS) states that they do not know if a significant amount of sediment is being reduced from entering their intended project after the investment in numerous sedimentation traps in the watershed, making it difficult to determine the cost effectiveness of the feature.

- The sediment control traps constructed in the watershed for both projects are on a volunteer basis. Farmers are approached by NRCS, but no control is used in getting a farmer to construct a trap on his property, even though his/her farm may be contributing significant amounts of sediment to the project. A systematic approach to determining the largest source of the sediment and then prioritizing and funding appropriately would be helpful. From a watershed perspective - did we put them in the right spot? Targeting the largest contributing sources is essential.

- Both projects have farmers that the NRCS has turned away in the project watershed, because of the limited project dollars. The program was slow to begin when the NRCS was first engaged on Swan Lake. At first, farmers were reluctant to build sediment traps out of the perception that the Government would be using their land. By the time the Batchtown project started, farmers were volunteering to build sedimentation traps after seeing how the program was administered across the Swan Lake watershed.

- The NRCS can build the sedimentation traps cheaper than the Corps because their construction contracting procedures are more flexible. The NRCS was a great partner.

8.3.3. References

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8.3.4. Case Studies. Upland sediment control measures have been implemented at the Swan Lake and Batchtown HREP projects.

ISLANDS

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CHAPTER 9

ISLANDS

9.1 Resource Problem

The Upper Mississippi River (UMR) 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. Table 9.1 shows the effect of submergence on parameters describing hydrodynamics, sediment transport, and geomorphology in the lower reaches of navigation pools. A more detailed discussion on these physical changes can be found in Appendix C.

Appendices to this chapter include a discussion on Physical River Attributes (Appendix A); Habitat Parameters (Appendix B); Engineering Considerations (Appendix C); Project Photographs (Appendix D); and Standard Details (Appendix E).

Table 9.1. Lock and Dams Effects and Island Effects on Parameters Describing Hydrodynamic, Sediment Transport, and Geomorphic Regimes in the Lower Reaches of Pools in Pools 1 Through 13 of the UMRS

Parameter	**Definition**	**Lock and Dam Effects**	**Island Effects**
Q_c	Channel discharge including secondary channels	- [1]	+ [2]
Q_f	Floodplain discharge	+	-
Q_t	Total river discharge		
Q_c/Q_t	Ratio of channel discharge to total discharge	-	+
Q_f/Q_t	Ratio of floodplain discharge to total discharge	+	-
v_c	Channel velocity	-	+
v_f	Floodplain velocity	+	-
W_c	Channel width including secondary channels	+	-
z_c	Channel elevation	+	-
z_f	Floodplain elevation	+, -	+, -
Δz_w	Difference in elevation between the two-year flood and low flow	-	
F	Wind fetch in floodplain	+	-
Q_s	Sediment load	-	+
SS	Suspended sediment concentration	+	-
D_c	Sediment deposition rate in channels	+, -	-
D_f	Sediment deposition rate in floodplains	+	-
E_c	Channel bed erosion rate	-	+
E_b	Bankline erosion rate	+	-
E_f	Floodplain erosion rate	+	-
d_{50}	Sediment particle size in channels	-	+

[1] + indicates that magnitude of parameter increased
[2] - indicates that magnitude of parameter decreased

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

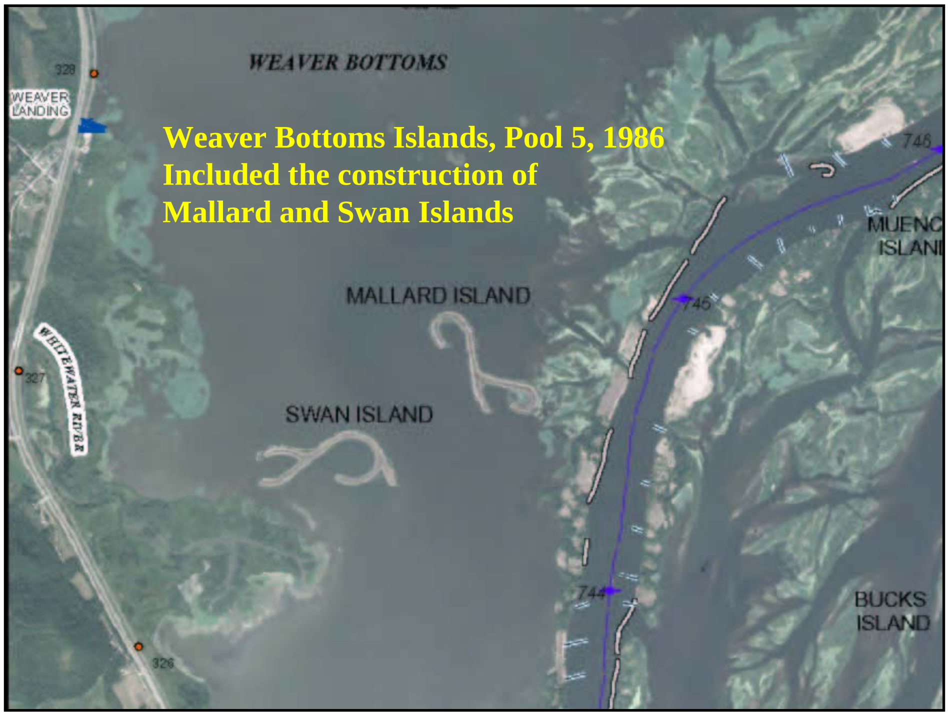
Sediment Deposition. With permanent submergence in the lower reaches of the navigation pools came the continual flow of water into the floodplain areas. As flow spread out in the backwaters, it lacked the energy to transport sediment through the backwaters, resulting in a depositional system. Sediment 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.

Island Erosion. The islands that remained after the locks and dams were constructed were exposed to erosive forces from wind driven wave action, river currents, and ice action. As islands eroded, 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.

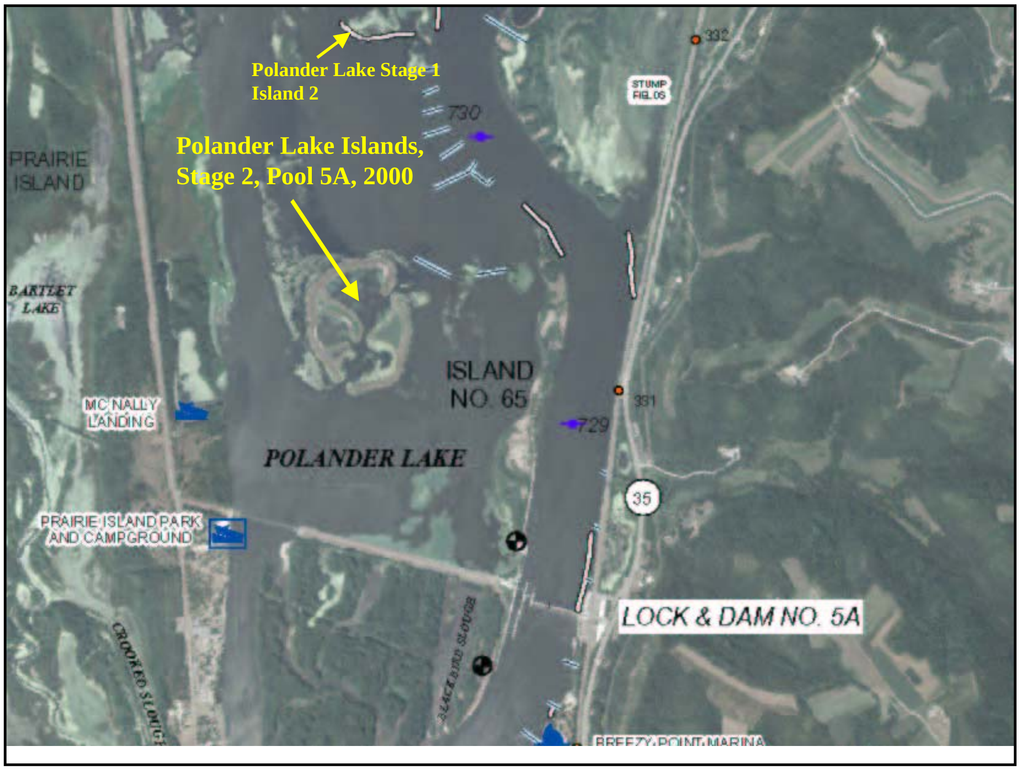
The effects of sediment deposition, loss of aquatic plant communities, and island erosion has resulted in degraded habitat in the lower reaches of the navigation pools. While project goals and objectives usually focus directly on the improvement of habitat in the floodplain, the physical impact of island construction is to partially restore riverine hydrodynamic, sediment transport, and geomorphic conditions. As table 9.1 illustrates, islands reverse many of the effects of lock and dam construction. A new island essentially becomes the new natural levee, separating channel from floodplain, reducing channel-floodplain connectivity, and increasing channel flow while decreasing the amount of floodplain flow. This increases the velocity and transport of sediment in adjacent channels. Wind fetch and wave action is reduced in the vicinity of islands, reducing the resuspension of bottom sediments, floodplain erosion, and shoreline erosion. Earlier islands were designed to reduce the supply of sediment to the floodplain, potentially decreasing floodplain sediment deposition. More recent island projects have taken a more realistic approach toward “managing” sediment transport and deposition by designing islands to promote both scour and deposition as a means to improve sustainable habitat quality and diversity. Constructing islands (or natural levees) is a necessary step in restoring the form, function, and habitat value in the lower portions of the navigation pools.

9.2 Plan Views of Island Projects

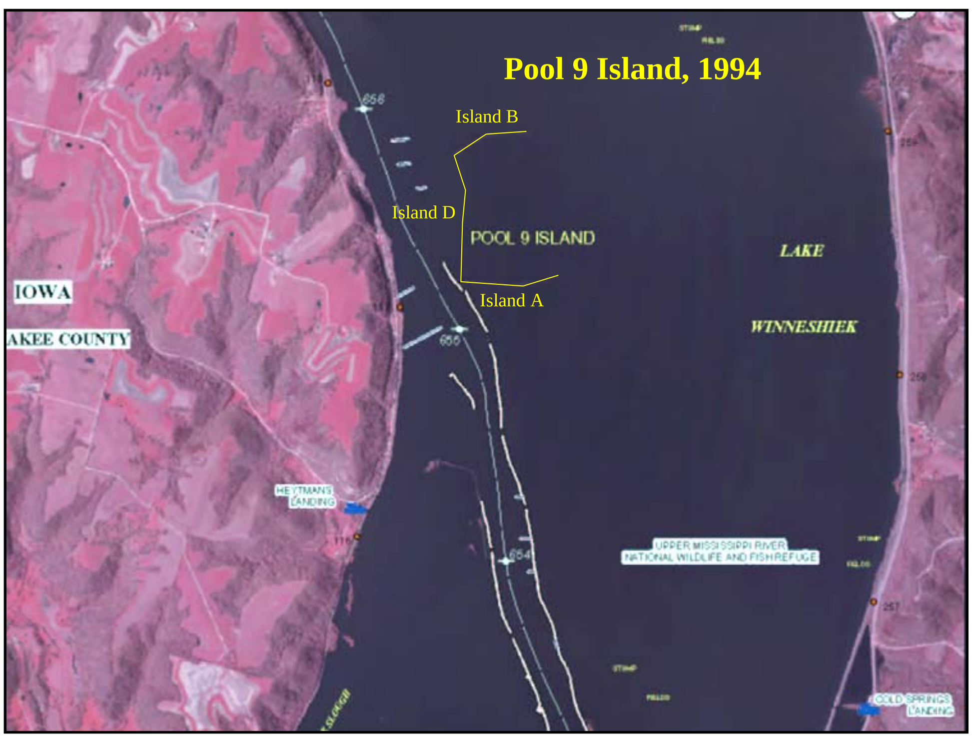


Photograph 9.1. Weaver Bottoms Island, Pool 5, Mississippi River

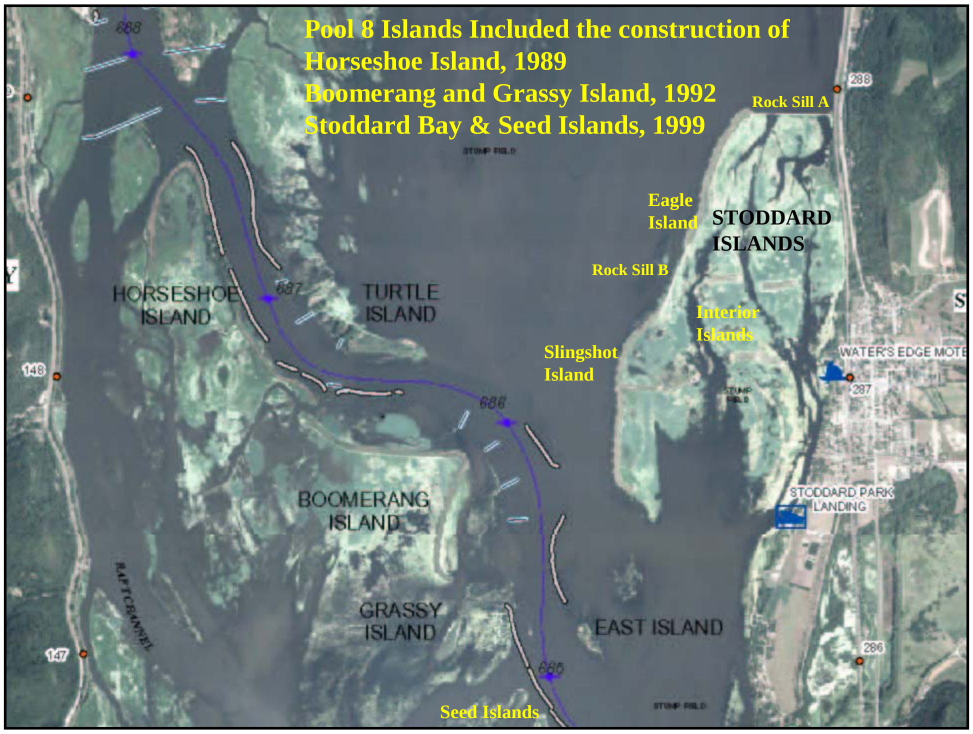
Photograph 9.2. Lake Onalaska Islands, Pool 17, Mississippi River



Photograph 9.3. Polander Lake Islands, Pool 5A, Mississippi River



Photograph 9.4. Pool 9 Island, Pool 9, Mississippi River



Photograph 9.5. Pool 8 Islands, Pool 8, Mississippi River

Photograph 9.6. Willow Island

Photograph 9.7. Peoria Lake Islands, Peoria Pool, Illinois River

Photograph 9.8. Pool 11 Islands, Sunfish Lake, Mississippi River

Photograph 9.9. Swan Lake Islands, Illinois River

9.3. Engineering, Design, and Construction Data for Existing Island Projects

9.3.1. Island Cross Section. Figure 9.1 shows a typical island cross section (though many exceptions exist). Islands have a main section (dimension c) with berms on either side (dimensions a & e). The elevation and width of the main section is a function of habitat objectives, engineering considerations such as flood conveyance needs, economics, stability, and lessons learned. Early designs in the mid to late 1980s resulted in islands constructed to a 10-year flood elevation or higher. The higher islands, it was believed, would be more stable due to less frequent overtopping and provide a greater barrier to sediment laden flow from the main channel, reducing sediment deposition in backwaters. With the occurrence of several floods in the 1990s, it became apparent that islands were stable during overtopping events as long as the head differential from one side to the other was less than 0.5 feet and as long as there was topsoil and vegetation on the island. This led to lower design elevations. The berms are constructed to an elevation between 1 and 2 feet above the average water surface elevation. They provide sacrificial sand for beach formation, which occurs due to wave action, and substrate for willow growth, which prevents erosion of the main section of the island during flood events. Because the berms are usually lower than the main section of the island, they provide elevation diversity also.

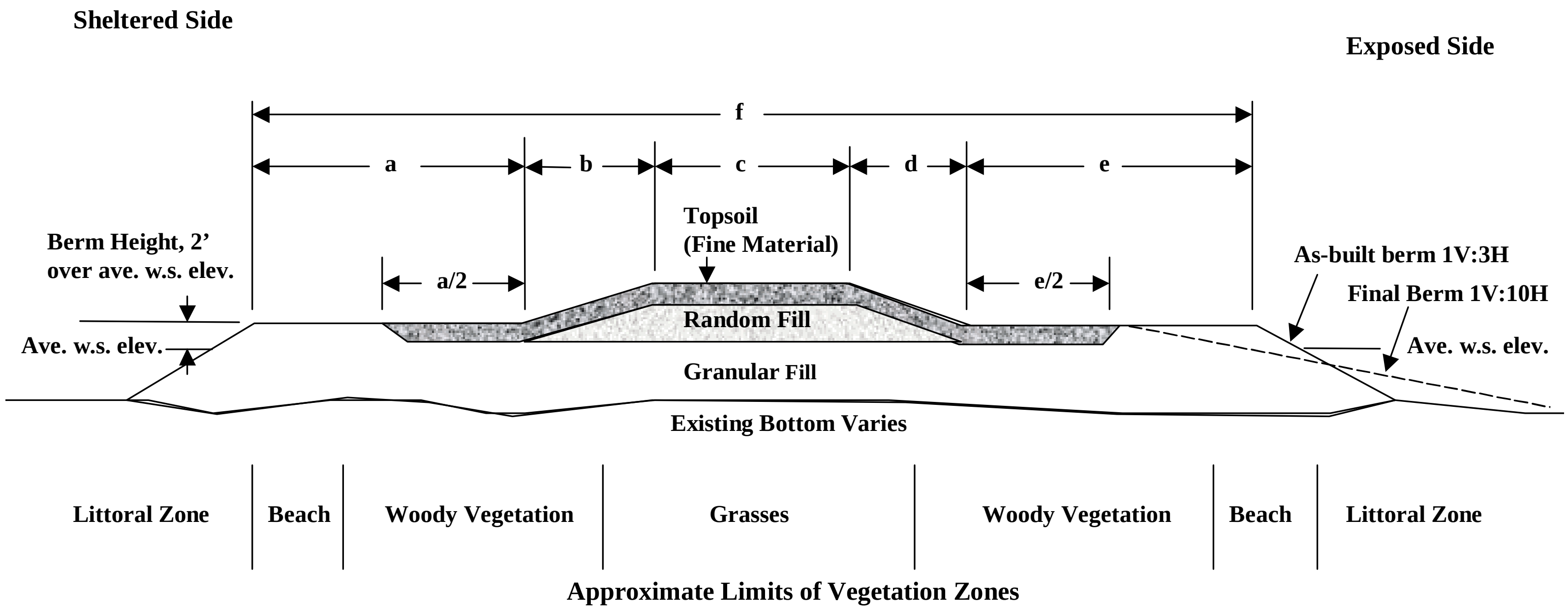


Figure 9.1. Typical Island Cross Section

Islands in the northern reaches of the UMR are usually constructed with sand (granular fill) and mixtures of fine sediments and sand. The mixtures are called by various terms including fine material, random fill, topsoil, fines, and select fines. Fine sediments are defined as silts and clay size material passing the no. 200 sieve or the .075 mm sieve. Table 9.2, which provides information on the quantities of sand and fines that were used on three island projects, indicates that islands consist of approximately 75 percent sand and 25 percent fines. The base of the island is constructed of sand to provide a stable work surface for construction equipment; then mixtures of fine sediments and sand are placed on top of the sand as random fill or as a fine material layer that acts as topsoil (photograph 9.10).

Table 9.2. Sand and Fines Quantities on Three Island Projects

	Pool 8, Phase I	**Pool 8, Phase II**	**Polander Lake**
Island Length (feet)	8,700	10,400	9,200
Sand (cubic yards)	157,000	207,000	176,000
Random Fill (cubic yards)			33,000
Fine Material (cubic yards)	56,000	66,000	30,000
Total Fill (cubic yards)	213,000	273,000	239,000
Percent Sand	74	76	74
Total fill/foot of length (cubic yards)	24.5	26.3	26.0

Photograph 9.10. Pool 8, Phase I, Stage II, Boomerang Island
Fine sediments have been placed on top of a sand base to form a topsoil layer. These fine sediments were mechanically excavated and placed on the island (as opposed to hydraulic placement)

Because of a difference in material types, islands in the southern reaches of the UMR and Illinois River have been constructed using fine sediments (i.e. no sand base). At both Peoria Lake and Swan Lake, islands were created from sediment that was dredged mechanically from nearby channels. The specifications for both of these projects called for the contractor to use a large bucket (e.g. 7 CY at Peoria Lake) for mechanical excavation. This was done so that the fine sediments would be placed in larger masses, preserving some of the cohesive strength of the sediments and preventing fluidization. The side slopes of these islands were also flattened (1V:6H at Swan and Peoria Lake) to add more stability to the islands. The islands at Peoria Lake were constructed in three lifts. Information regarding properties of the borrow material, such as percent fines, is not available.

Table 9.3 provides design dimensions for constructed island projects. The variables “a” through “f” are as shown in figure 9.1. The top elevation is listed and the corresponding flood that would overtop that elevation. The two side slopes that are listed are for the exposed or channel side and the sheltered or floodplain side of the island. The distribution of top elevations versus flood frequency is shown in figure 9.2. Generally, top elevations have decreased with each successive project, and the variability of elevations has increased.

Table 9.3. Island Cross Section Dimensions

Project	a	b	c	d	e	f	Height Above Normal Pool and Flood Time of Return	Side Slopes V: H	Island Length and Reach Description (ft)	Year
Weaver Bottoms	0	32	100	32	0	164	8, 80-yr	1:4 1:4	8700	1986
Lake Onalaska	0	18	50	9	20	100	6, 20-yr	1:3 1:3	3900, 3 islands at 1300 feet each	1989
Pool 8, Phase I, Stage 1, Horseshoe Island	0	20	50	30	30	130	4, 10-yr	1:5 1:10	2100, from head down each leg	1989
	0	20	75	30	30	155	4, 10-yr	1:5 1:10	800, middle west leg	1989
	0	20	30	40	0	90	4, 10-yr	1:5 1:10	600, lower west leg	1989
Bertom McCartney										1992
Pool 8, Phase I, Stage 2, Boomerang Is.	30	12	50	12	30	134	3.8, 10-yr	1:5 1:5	7000	1992
	20	12	50	12	20	114	3.8, 10-yr	1:5 1:5	700, several reaches	1992
	30	10	50	40	0	130	3.8, 10-yr	1:4 1:10	500, large fines section	1992
	0	25	30	25	0	80	5, 17-yr	1:5 1:5	500, lower Horseshoe Island	1992
Pool 8, Phase I, Stage 2, Grassy Island	0	6	50 -150	6	0	62 - 162	2, 5-yr	1:3 1:3	900	1992
Pool 9, Island A & B [2]	na	3.4	5	3.4	na	12	1.5, 1.6-yr	1:1.7 1:1.7	3800	1994
Pool 9, Island D [2]	na	2	5	2	na	9	.5, 1.3-yr	1:2 1:2	2900	1994
Polander Lake, Stage 1, Island 2 [2]	na	9	4	9	na	22	2, 1.8-yr	1:3 1:3	1100	1994
Willow Island	30	25	10	21	0	86	7, 10-yr	1:5 1:3	2800	1995
	0	17	10	21	0	48	7, 10-yr	1:2.51:3	900, riprap reach	1995
Peoria Lake Islands	0		50		0		8	1:6	5280	1996
Swan Lake, Illinois River	0	45	25	45	0	115	5	1:6 1:6	9 islands 180' to 500' long	1996
Pool 8, Phase II, Eagle Island	33	13	50	13	33	142	4, 10-yr	1:5 1:5	2800	1999
Pool 8, Phase II, Slingshot Island	33	8	33	8	20	102	3, 7-yr	1:5 1:5	3300, Upper Slingshot Island	1999
	33	7	33	7	33	113	2.7, 6-yr	1:5 1:5	1200, Middle Slingshot Island	1999
	33	3	33	3	33	105	2, 5-yr	1:5 1:5	900, Lower Slingshot Island	1999
Pool 8, Phase II Interior Islands	33	13	33	13	20	112	4, 10-yr	1:5 1:5	2400	1999
Pool 8, Phase II Rock Sills [2]	na	6	13	3	na	22	1, 2.5-yr	1:4 1:2	2500	1999
Polander Lake, Stage II	40	17.	20	17.	30	125	5, 4-yr	1:5 1:5	3800	2000
	40	27.	20	27.	30	145	7, 8-yr	1:5 1:5	1200	2000
Polander Lake, Stage II, Interior Islands	20	20	20	12	20	92	3.5, 2.5-yr	1:5 1:3	4200	2000
Pool 11 Sunfish Lake									5000	2004
Pool 11, Mud Lake								1:5 1:5		2005
Spring Lake, Island 2	20	5	40	5	45	115	3, 8-yr	1:5 1:5	2400	2005
Spring Lake, Island 3	20	10	45	10	30	115	4, 15-yr	1:5 1:5	850	2005
Spring Lake, Island 3	40	0	65	0	40	145	2, 6-yr	-	1400	2005
Spring Lake, Island 3	0	0	60	0	0	60	2.5, 7-yr	-	1250	2005
Spring Lake, Island 4	0	0	115	0	0	115	662.5, 7-yr	-	2050	2005

[1] Note: Elevations are NGVD, 1912 adj. Dimensions are in feet.
[2] These islands were constructed entirely of rock.

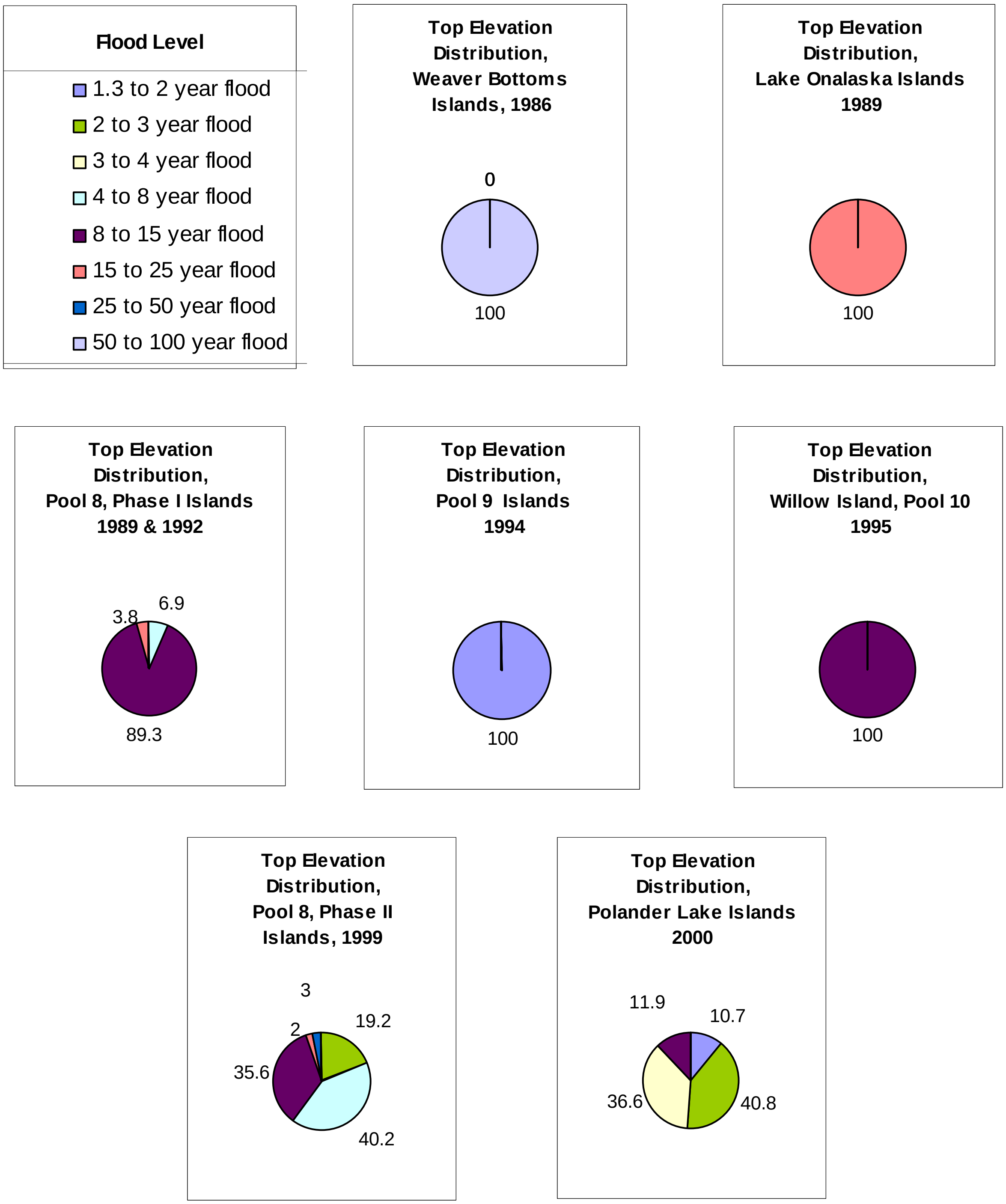


Figure 9.2. Distribution of Top Elevations Based on Flood Frequency for Constructed Island Projects

Islands are planted with or are naturally colonized by woody and herbaceous plants that stabilize the island and provide habitat (photograph 9.11). The four vegetation zones that can occur on islands include grasses (and sometimes woody vegetation) on the higher main section of the island, woody vegetation on the low elevation berms, a beach zone that doesn't have vegetation due to wave action or ice action, and a littoral zone just below the water surface along the shoreline. Depending on a variety of factors, one or more of these zones may be absent. For instance, low elevation islands tend to be colonized with woody vegetation across the entire island, eliminating the grasses. Shorelines in sheltered areas may have woody vegetation right to the waters edge, eliminating the beach zone.

Photograph 9.11. Pool 5, Weaver Bottoms, Swan Island
Native prairie grasses were planted to provide nesting habitat and stabilize the top of the island.

Fish and wildlife habitat goals and objectives have become more diverse over time with a focus on many different species, resulting in greater variation in island elevation, cross section, and vegetative plantings. The Lake Onalaska Islands constructed in 1989, consisted of a single uniform cross section throughout the project and one vegetation scheme, while the Polander Lake Island project, constructed in 2000, consisted of six different cross sections, six different tree and shrub planting schemes, and four different grass/forb planting schemes.

9.3.2 Vegetation and Topsoil. The top, side slopes, and a portion of the berm are capped with topsoil and planted with vegetation. Topsoil (which is labeled as fine material in figure 2) has cohesive properties, which resists erosive forces and provides substrate for vegetation. Vegetation reduces erosive forces before they cause erosion on the islands and provides habitat. Habitat benefits include nesting cover, food, and shelter associated with prairie grass communities. In 1993 and 2001 recently constructed islands with little or no vegetation were overtopped by floods before significant vegetation could be established on them. In cases where a layer of topsoil had been placed on the island, erosion was usually minimal. When topsoil had not been placed and sand was exposed to wave action and/or river currents during the flood, significant erosion usually occurred. To maintain sandy substrate for turtle nesting, small sections of the Pool 18,Phase II Islands were constructed at a higher elevation and did not have topsoil placed on them. Several of these turtle nesting sections were severely eroded when they were overtopped by 1 to 2 feet of water during the 2001 flood, which was an 80-year flood event). Photograph 9.12 shows open water where there once was a sand section. The adjacent island sections, were stable because of the topsoil and grass growing on them. The fix that was implemented here was simply to line the existing cut with rock or cobbles so that it wouldn't get any larger. At the Swan Lake project on the Illinois River, vegetation that was planted on the islands was quickly grazed by waterfowl leaving these islands relatively bare during the first few years after construction. Protecting the island vegetation with bird netting or other techniques until the vegetation has matured adequately would have improved conditions on the island.

Photograph 9.12. Pool 8, Phase II, Slingshot Island

Islands constructed prior to 1990 in the northern half of the UMR, consisted of a sand core with a layer of topsoil spread over the sand. Boomerang Island, constructed in 1992, had a sand base that was one to two feet above the average water surface. The higher portion of the island consisted of up to a 4-foot layer of sediment with at least 50-percent fines. The Pool 8, Phase II Islands consisted of a sand base, with a 1 to 3 foot thick upper layer of random fill that was required to have more then 5-percent fines, capped by a 12" layer of select fines that had at least 40-percent fine sediments in it. The Polander Lake Islands were designed in a similar fashion with a sand base, topped by a layer of fill with no requirements on the fines, which in turn was capped by a 12" layer of material with a fines content of between 40 and 70 percent. Anfang and Wege (2000) concluded that there should be an upper limit to the percent fines contained in the topsoil, because material with too much fines tends to harden and become impermeable to rain infiltration. Therefore, the specification of 40 to 70-percent used at Polander Lake probably represents the standard as of this date. There remains some debate as to the thickness of topsoil that is needed and with topsoil accounting for as much as 25-percent of project costs, reducing thicknesses even by a few inches can reduce costs significantly. However, there is a desire to maximize the use of fines dredged from backwaters since this dredging increases backwater depth creating fish habitat. In addition, if island stability or the establishment of woody vegetation is the primary criteria, experience suggests that a thicker layer of topsoil is desirable.

Table 9.4 provides information on the thickness and gradation of the topsoil and random fill layers on islands. One foot of topsoil has become the standard thickness to assure adequate coverage, good plant growth, and island stability.

Anfang and Wege measured the percent fine sediments in the topsoil of various islands and found: 27 and 32 % on Swan and Mallard Island in Pool 5, 37, 38, and 51 % on Broken Gun, Cormorant, and Arrowhead Islands in Pool 7, and 42 and 36 % on Horseshoe and Boomerang Islands in Pool 8. USACE surveys indicate a clay, silt, sand fraction that averaged 61, 27, and 12 percent for surface substrate on Boomerang Island based on 5 samples. The reason for the discrepancy with Anfang and Wege is not known, but may be related to differences in the sampling technique (i.e. a surface grab sample will tend to have fewer fines than a deeper core).

The choice of grasses or legumes planted on islands is based on habitat management objectives, not on erosion resistance. Obviously the establishment of vegetation increases stability, however, if adequate topsoil has been placed, island erosion during overtopping has been minimal, and the specific type of vegetation doesn't seem to be a significant factor. Most of these islands have been planted with various mixtures of native prairie grasses and legumes (photograph 9.13). A variety of conditions existed on the Polander Lake Islands 4 years after they were constructed and 3 years after planting. Fairly dense cover with good species diversity can be seen in the foreground. Areas of bare soil can also be seen. The people in the photograph are walking on the berm on the sheltered side of the island.

Anfang and Wege (2000) conducted extensive surveys of the vegetation communities on island projects and dredge material sites. They developed recommendations for site management based on their observations that can be used as a guide in choosing vegetation types for islands. Given that all sites tend to be colonized by woody vegetation eventually, they suggest that design factors such as the thickness of fine material, percent fines in topsoil, species selection, and island elevation be more rigorously tested to determine how to maintain grassland cover over time. Management activities such as controlled burning, fertilization, mowing, or second seedings were suggested to maintain grasses. Some of their recommendations are summarized in habitat parameter 4 later in this report. Nissen (pers. comm.) has observed that overtopping of islands during floods introduces new plants that colonize the island and usually displace the planted vegetation. Based on his observations, the use of expensive seed mixes on islands that will be overtopped or islands that aren't going to be managed to maintain the vegetation is questionable.

Table 9.4. Topsoil and Random Fill Thickness and Gradation

Project	Island Length (feet)	Topsoil Thickness (inches) and Minimum Percent Fines	Random Fill Thickness (inches) and Minimum Percent Fines	Year Constructed
Weaver Bottoms	8700	6		1986
Lake Onalaska	3900 (1300 each)	6 to 12		1989
Pool 8, Phase I, Stage 1, Horseshoe Island	3450	4 to 8		1989
Pool 8, Phase I, Stage 2, Boomerang Island	8175	48, 50-percent fines		1992
Pool 8, Phase I, Stage 2, Horseshoe Island	490	24 to 36		1992
Pool 8, Phase I, Stage 2, Grassy Island	900	6 to 12		1992
Willow Island	3700	6		1995
Pool 8, Phase II, Eagle Island	2800	12, 40-percent fines	48, 5-percent fines	1999
Pool 8, Phase II Upper & Middle Slingshot Island	4440	12, 40-percent fines	36, 5-percent fines	1999
Pool 8, Phase II, Lower Slingshot Island	910	12, 40-percent fines	24, 5-percent fines	1999
Pool 8, Phase II, Interior Islands	2350	12, 40-percent fines	48, 5-percent fines	1999
Polander Lake	5300	12, 40 to 70-percent fines		2000

Photograph 9.13. Polander Lake Islands

One of the primary purposes of the berm is to provide conditions for the growth of woody vegetation, which reduces wave action on higher parts of the island during floods. Although colonization by woody plants will occur naturally, sandbar willow 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.

9.3.3 Shoreline Stabilization. A shoreline stabilization plan that involves the use of vegetation, rock, logs, synthetic grids, or some combination of living and inert materials is needed for all projects. At the Weaver Bottoms, Swan Lake, and Peoria Lake, unprotected shorelines were severely eroded following construction. The primary forces that affect island 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 of islands includes riprap (photograph 9.14), biotechnical methods (photographs 9.15 and 9.16) and vegetative stabilization (photograph 9.17).

Photograph 9.14. Lake Onalaska - Riprap and Geotextile Filter Placed on Sand

Photograph 9.15. Pool 8, Phase II, Boomerang Island - Biotechnical Stabilization with Groins and Willows

Photograph 9.16. Weaver Bottoms, Swan Island -
Biotechnical Stabilization with Fiber Rolls, Sand Bags and Willow Mats

Photograph 9.17. Pool 8, Phase II, Boomerang Island
Vegetative stabilization was used on over 60% of the shorelines on Boomerang Island.

A description of these techniques is given in table 9.5. In this document, the use of groins, vanes, and offshore mounds along sand berms that are planted with willows is considered biotechnical stabilization.

Table 9.5. Description of Shoreline Stabilization Techniques Used on Island Project

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 as follows:

Feature	Function
Groins	Contain littoral drift (i.e. the transport of sand along a shoreline due to wave action) 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

In most island designs, near-shore berms are constructed along either side of the island (Figure 2). Near-shore berms eliminate or reduce erosive forces so that erosion of the main section of the island 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 main portion of the island. During high water conditions, the woody vegetation that grows on near-shore berms reduces erosive forces on the island main section.

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 9.6 lists the length of various types of shoreline stabilization used on islands that have been constructed. 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 projects tend to have less riprap and more use of biotechnical and vegetative stabilization.

The rock gradation used for riprap and groins is given in table 9.7. 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 islands. The large gradation has been used on several projects where wind fetch exceeded 2 miles, or where ice action was expected to be a problem. It has also been used to discourage people from moving rocks. 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.

9.3.4 Cost. The cost of the three most recent island projects, Pool 8, Phase I and II, and Polander Lake, is shown in table 9.8 .

The rock sills constructed as part of the Pool 8, Phase II project were very expensive. They were constructed with a top width of 4 meters (13 feet) so that if scour did occur at the toe of the sills, there would be enough rock to allow for self-healing. A geotechnical membrane placed in the upstream sill to reduce seepage increased the cost by a nearly a factor of two. The inclusion of this the geotechnical membrane was effective at virtually eliminating seepage through the structure allowing target discharges to be met the first year of the project without any modification to the project.

Material costs for earth islands are given in table 9.9. Granular fill, fines, and rock account for 75 to 95-percent of the cost of earth islands. Establishing turf and planting willows or trees usually account for less than 10-percent of the costs.

Table 9.6. Shoreline Stabilization Length and Percent of Total Length Used on Island Projects

Island	**Total Shoreline Length (feet)**	**Riprap Stabilization Length**		**Biotechnical Stabilization Length**		**Vegetative Stabilization Length**		**Year Constructed**
		feet	**percent**	**feet**	**percent**	**feet**	**percent**	
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
Average			19%		38%		43%	

Table 9.7. Rock Gradations Used on HREP Projects

	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

Table 9.8. Costs of the Pool 8, Phase I and II and Polander Lake Island Projects

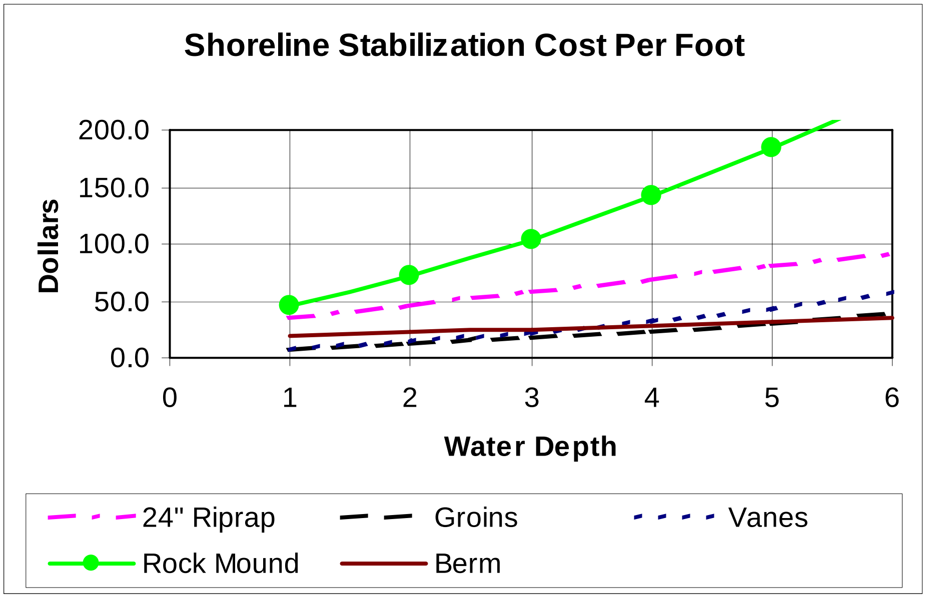
Project	Year Constructed	Feature	Length (feet)	Cost (dollars)	Cost/Foot
Pool 8, Phase I, Stage 2	1992	Earth Islands	9,600	$1,456,000	$151
		Earth Islands	10,600	$1,755,000	$165
		Rock Sills	2,500	$ 722,000	$288
		Seed Islands	1,280	$ 169,000	$132
Pool 8, Phase II	1999	Total Cost		$2,646,000	
Polander Lake, Stage 2	2000	Earth Islands	9,200	$1,897,000	$206

Table 9.9. Material Costs for Earth Islands [1]

Island Project	Earth Island Cost ($1000)	Granular Fill	Fines	Random Fill	Rock Shore Protection	Turf	Plantings: willows, trees, shrubs, etc	Mob/ Demob	Geo-textile	Loafing Structure
Pool 8, Phase I, Stage 2	1,456	$5.46/yd[2] 855 59%	$6.95/yd[2] 389 27%	N/A	$14.50/ton 140 10%	$1250/ac 22 1.5%	20 1.1%	*	2.50/yd[3] 18 1.2%	N/A
Pool 8, Phase II	1,707	$2.88/yd[2] 501 29 %	$4.70/yd[2] 238 14 %	N/A	$33/ton 550 32%	$2491/ac 47 3%	148 9%	186 11%	3.85/yd[3] 37 2%	N/A
Polander Lake, Stage 2	1,819	$2.90/yd[2] 518 28%	$17.50/yd[2] 538 30%	$2.55/yd[2] 93 5%	$35/ton 372 20%	$1990/ac 31 2%	53 3%	177 10%	3.40/yd[3] 14 1%	14 1%
Peoria Lake				$2.00/yd[2]						
Pool 11 Islands				$10.90/yd[2]						

[1] In each box the top number is the unit costs, the middle number is the total dollar amount paid the contractor for each material (in thousands of dollars), and the bottom number is percentage of the total earth island cost paid for each type of material. Dollar amounts are based on the base contract amounts for earth islands with adjustments made for modifications during construction. These values were obtained from the contract bid forms found in the final contract report for each project. Expenditures not related to earth island construction (e.g. seed island construction) are not included. No adjustments were made due to inflation to obtain a present value.
[2] cubic yards
[3] square yards
* The Pool 8, Phase I, Stage 2 contract had no separate bid item for mobilization and these costs are most likely reflected in the higher sand granular fill unit cost.

Shoreline stabilization costs include earth fill (granular and fines) for the berm, rock, and the cost of willow plantings. Figure 9.3 shows estimated costs for constructing various types of 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. Groins and vanes are the cheapest stabilization option, regardless of water depth. Rock mounds are the most expensive option in all cases. The cost for planting willows was assumed to be $2 per linear foot based on the bid prices for the Pool 8 Phase II and Polander Lake projects (table 9.10).



Assumptions
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.

Figure 9.3. Shoreline Stabilization Costs Per Foot of Shoreline

Table 9.10. Cost of Willow Plantings on Two Island Projects

Project	Bid Price	Shoreline Length (f)	Cost Per Foot
Pool 8, Phase II	$29,000	19,300	$1.50
Polander Lake	$8,400	3,750	$2.24

9.4 Lessons Learned

Many lessons have been learned during the design, construction, and maintenance of island projects. Several major floods have occurred during the 20 years that the islands have been in existence, providing valuable information on project durability, maintenance requirements, and rehabilitation methods. Lessons learned regarding biological response have been developed by monitoring the change in abundance of aquatic vegetation, fish, and wildlife. Using lessons learned is an important aspect of habitat project design since the experience gained from past projects can be used to improve future designs. Tables 9.11 through 9.17 list lessons learned from previous projects. There are seven different tables—six that cover different design categories and a separate table for constructability. The numbering system for the lessons learned is illustrated below. The six design categories are designated by the numbers 1 through 6, and the 14 projects are designated by the letters A through M.

1.B.3

Design Category

1. Layout
2. elevation
3. width
4. side slope
5. topsoil & vegetation
6. shoreline stabilization

Project

A. Weaver Bottoms
B. Lake Onalaska
C. Pool 8, Phase I, Stage 1
D. Pool 8, Phase I, Stage 2
E. Pool 9
F. Polander Lake, Stage 1
G. Willow Island, Pool 10
H. Pool 8, Phase II
I. Polander Lake, Stage 2
J. Swan Lake, Illinois River
K. Spring Lake Islands, Pool 5
L. Peoria Lake, Illinois River
M. Bertom McCartney
N. Pool 11 Islands

Lesson Learned

Table 9.11. Lessons Learned, Design Category 1- Island Layout

Project	Year Constructed	Lessons Learned
Weaver Bottoms	1986	1.A.1 Islands that shelter shallow water areas increase the aquatic vegetation response in those areas. Swan and Mallard Islands sheltered primarily deep areas (e.g. depths greater than 3') and produced a limited aquatic vegetation response in those areas. Several sheltered bays were created by this island layout, however the only significant vegetation response occurred in the shallow portion of the southern most bay of Mallard Island. 1.A.2 Islands in deep water have a high erosion rates. The deep water these islands were placed in resulted in excessive shoreline erosion due to the amount of sand transported offshore during beach building.
Lake Onalaska	1989	1.B.1 Low velocity deposition zones were created both upstream and downstream of Arrowhead island, while high velocity erosion zones were created to either side of the island (USGS-UMESC, Biological Response Study, Lake Onalaska). By positioning islands perpendicular to the primary flow path, the size and magnitude of these zones was increased. 1.B.2 By positioning islands perpendicular to the primary wind direction, the size of the downwind sheltered zone was maximized. 1.B.3 Islands provide suitable habitat and offer protection to: Macrophytes (if water depths are three feet or less) Fish for use as a nursery area Finger Nail Clams Diving ducks that fed on the Finger Nail clams (USGS, Biological Response Study, Lake Onalaska). 1.B.4 Islands isolated from human disturbance provide more waterfowl nesting opportunities. Broken Gun Island, which experiences significantly more human disturbance than Cormorant or Arrowhead Island, had a much lower nesting success rate than either of the other two islands. 1.B.5 Vegetation sampling done by the WDNR at Arrowhead Island in 1997 documented the presence of extensive aquatic vegetation beds along the shallower (depth < 3') western half of the island. The vegetation response along the deeper eastern half of the island was not as good. 1.B.6 Islands in deep water have a high erosion rates. The deep water that portions of these islands was placed in resulted in excessive shoreline erosion due to the amount of sand that was transported offshore during beach building. A wider berm should have been used in order to provide additional sacrificial material for beach establishment. See *Engineering Consideration 6* for a description the beach formation process.

Table 9.11. Lessons Learned, Design Category 1- Island Layout

Project	Year Constructed	Lessons Learned
Pool 8, Phase I, Stage I Horseshoe Island	1989	1.C.1 The shallow off-shore water depths along portions of this island eliminated the need for rock protection. During the hydraulic placement of dredge material for this island, the resulting island slope was so flat that it formed a berm and no further shaping or protection was required. 1.C.2 Placement of islands a distance back from the navigation channel (100 to 300 feet) allowed for shallow water depths to dampen towboat and recreation boat waves before reaching the berm of the island, therefore reducing the need for additional bank stabilization.
Pool 8, Phase I, Stage II Boomerang	1992	1.D.1 The shallow off-shore water depths (less than 1 foot deep) along portions of this island eliminated the need for rock protection. 1.D.2 The design team should do an on-site inspection of the project layout before finalizing plans and specs. The centerline of Boomerang Island was staked and inspected, resulting in several adjustments that improved island position and avoided changes during construction. 1.D.3 Access channel dredging accounted for a significant percentage of the fine material placed on the island, reducing beneficial backwater dredging. Several of the access channels at Boomerang Island exceeded 500’ in length. 1.D.4 Placement of islands a distance back from the main channel allowed for shallow water depths to dampen towboat and recreation boat waves before reaching the berm of the island, therefore reducing the need for additional bank stabilization. 1.D.5 Islands do affect sediment transport within the floodplain. Shortly after construction, deposition was observed along the north south leg of Boomerang Island and in the vicinity of Heron and Trapping islands downstream of the project area. The deposition occurring in the Heron and Trapping islands area was the catalyst leading to the development of seed islands constructed by the agencies under separate funding and later as part of Pool 8 Islands, Phase II.
Pool 9 Islands	1994	1.E.1 Field surveys of the hydraulic conditions in the project area improved the final design. The conceptual plan was to build islands to prevent the inflow of water and sediment from the main channel. Hydraulic surveys determined that flow in this area was actually from the backwater to the main channel and that wave action from the downstream direction was significant. This led to the inclusion of an island to reduce wave action from the south. 1.E.2 Restoring sheltered floodplain conditions resulted in significant growth of aquatic vegetation in the shallow interior area (less than 3 feet deep) bounded by these islands. These islands were laid out so that wind fetch from the northwest and southeast was reduced to less than 4,000 feet. The inflow to this area from the backwater was also reduced.

Table 9.11. Lessons Learned, Design Category 1- Island Layout

Project	Year Constructed	Lessons Learned
Pool 8, Phase II Stoddard Bay Islands	1999	1.H.1 Several island remnants existed along the alignment of the new islands. Rather than covering them up, the island alignment was adjusted so that the remnants would become part of the berm or would be located just offshore of the berm resulting in an aesthetic appearance and reducing erosion of the new island shoreline. 1.H.2 The criteria for backwater fish resulted in increases in fish population in Stoddard Bay (WDNR data). The objective was to create 200 acres of over-wintering habitat meeting the following criteria: Dissolved Oxygen levels > 3 mg/L Current velocity < .01 fps over 80-percent of area Water temperatures – 4°C over 35 % of area, 2-4° C over 30 % of area, 0-2° C over 35% of area. Water depths > 4 feet over 40 % of the area. 1.H.3 Restoring sheltered floodplain conditions resulted in significant growth of aquatic vegetation in the shallow interior area (less than 3 feet deep) bounded by these islands. The outer barrier islands reduced flow velocities in the shallow areas to less than 0.1 fps during the growing season and reduced wind fetch from the north and west to less than 4,000 feet. The interior islands were positioned to protect the shallow areas from southerly winds, reducing wind fetch from the south to less than 4,000 feet. 1.H.4 Two-dimensional hydrodynamic modeling played an important role in determining the final island layout. Rock sill dimensions and interior island locations were adjusted based on model results. 1.H.5. Sill heights were determined based on a balance between maximizing flood conveyance through Stoddard Bay, which would keep sill elevations low; and minimizing the occurrence of overtopping events during the November to March time period, which would keep elevations high. The elevation chosen limited November to March overtopping to 1 year in 10. SO far this seems to have been a reasonable design criteria. 1.H.6 The affects of ice cover on velocity was modeled and resulted in a change to the cross-section of the notch in upper rock sill. To account for ice affects, modeled velocities were adjusted based on the decrease in conveyance area that would occur from 2 feet of ice. WDNR monitoring indicates that the design goal of 50 cfs has been achieved.
Polander Lake	2000	1.I.1 Several isolated wetlands or bays were created as part of this layout to shelter the shallow interior area. The best response from vegetation, particularly emergents, was at Interior island No. 1, which had fines pumped into it to reduce the 2.5 to 3 foot water depths to about 1 foot. Water depths within the three interior islands were in the 2 1/2 - 3 foot range which is too deep for emergents except on the margins. However, floating-leaved aquatics like lotus and water lilies responded positively throughout the complex.
Spring Lake Islands	2005	1.K.1 The downstream end of Island 4, which was in deeper water, eroded rapidly after construction due to wind-driven wave action. This was a tapered section of the island and the narrower width increased concern that a breach might form across the island.

Table 9.12. Lessons Learned, Design Category 2 - Island Elevation

Project	Year Constructed	Lessons Learned
Weaver Bottoms Pool 5	1986	2.A.1 High islands take a long time to be colonized by woody vegetation (Anfang & Wege, 2000). In Weaver Bottoms, this is partly due to management efforts to maintain native prairie grasses on Swan Island through periodic burning. However, Mallard Island, which was not planted to prairie grasses, has not been colonized by woody vegetation either. These islands have a top elevation approximately 8 feet over the average water surface. 2.A.2 Low elevation berms (less than 2 feet above average water surface) that formed along portions of Swan Island during construction were rapidly colonized by woody plants. This did not occur elsewhere on either of the islands. Berms were not included in the design and formed accidentally in only a few locations due to site conditions.
Lake Onalaska	1989	2.B.1 The high elevation of these islands (6 feet over the average water surface) combined with periodic burning has maintained native prairie grasses on the islands delaying the conversion to woody vegetation. USFWS personnel (Nissen, pers. com.) feel that the higher elevation is the primary factor because the fuel load on these islands is insufficient to create a hot enough fire to kill the woody vegetation. 2.B.2 The higher elevation berms (approximately 3 feet over the average water surface) delayed the colonization of woody vegetation. Because of the excess dredge material, the berms on the Lake Onalaska Islands were constructed approximately 1 foot higher than the design elevation. This may have been one of the reasons that colonization by woody vegetation took a longer time.
Pool 8, Phase I Stage I Horseshoe Is	1989	2.C.1 High islands take a long time to be colonized by woody vegetation. The northern section of Horseshoe Island is retaining its grass cover and not converting over to herbaceous and woody vegetation. The as-built elevation of the west leg of this island is approximately five feet above the average water surface elevation 2.C.2 Significant portions of the backwater side of Horseshoe Island were less than 2 feet over the average water surface. Dense woody vegetation growth occurred on these areas right down to the pool level.
Pool 8, Phase I Stage II Boomerang	1992	2.D.1 Islands less than 5 feet above the average water surface elevation are more likely to convert to herbaceous and woody vegetation. Boomerang Island was constructed to an elevation of approximately 4.5 feet above the average water surface elevation. This island rapidly converted to woody vegetation. 2.D.2 Islands constructed to lower elevations are not exposed to severe erosive forces associated with floods as long as there is not a significant head differential across them. Grassy Island was constructed to an elevation of 633.0 (5-year flood elevation). During the 1993 flood (approximately a 15-year event) measurements over the top of this island indicated velocities less than 2 fps. In addition, wave action had no effect on the island due to the fact it was submerged by 3 feet of water. 2.D.3 The berms on Boomerang Island sloped from 2 feet over the average water surface where the berm attached to the main part of the island, to 0.5 feet over the average water surface at the outer edge. Dense vegetation growth occurred on these berms right down to the pool level. 2.D.4 Along the longitudinal profile, top elevations were decreased to match the water surface elevation. A 500’ reach at the upstream end of the project had a top elevation of 636. The elevation decreased to 635.0 over the next 2200 feet, and finally to 634.8 for the lowest 5900 feet. This may have been one of the factors that has limited erosion during floods, however there are several reaches of the island that have apparently settled and are overtopped before the rest of the island. 2.D.5 In several reaches, sand deposits during flood events have increased the top and berm elevations.

Table 9.12. Lessons Learned, Design Category 2 - Island Elevation

Project	Year Constructed	Lessons Learned
Pool 9 Islands	1994	2.E.1 Islands constructed to lower elevations are not exposed to the severe erosive forces associated with floods. These islands, which consisted of rock mounds, have been overtopped several times and show minimal damage.
Pool 8, Phase II	1999	2.H.1 The low rock sills combined with a stepped down island design resulted in a stable project during the 2001 flood, when the islands were less than 2 years old and didn't have well established vegetation. The rock sills were set at the lowest elevation, since they can withstand the erosive forces that typically occur during the initial stages of overtopping. Island elevations decrease in the downstream direction, so that, after the rock sills are overtopped, the downstream end is the first section of earth island that is overtopped, then the next section, etc. As each section of island is overtopped, it reduces the head differential on the next upstream section. 2.H.2 Islands constructed to lower elevations are not exposed to the severe wave action that occurs during floods. These islands were overtopped during the 2001 flood and minimal damage occurred. 2.H.3 Higher sections of island are exposed to higher erosion rates due to river currents and wave action. During floods, wind fetch increases significantly because lower features in the floodplain that normally break up wind fetch are now submerged. In addition, current velocities reach a maximum in floodplains and any feature that redirects flow (like an island), causes currents to accelerate resulting in erosion at the edge of the feature. The features on these islands constructed to higher elevations were severely eroded during the 2001 flood. Sand humps were included in this project to provide bare sand habitat for turtles. These humps varied in elevation from 636 to 638 (or 1 to 3 feet higher than the highest island section). The 2001 flood had a long crest with twin peaks that resulted in water surface elevations of 636 to 638 for up to 2 weeks. During this time wave action and river currents eroded all of the humps to some extent, with one of them completely scoured out to below pool elevations (629 to 630). The typical sections of islands that varied in elevation from 633 to 635 were stable. 2.H.4 During construction of the interior islands, the contractor discovered that excess material had been stockpiled on one of the islands. The design team decided that the excess material should be used to widen the berm and extend the length of the island. This would preserve the desired island elevations which were based on habitat considerations.
Spring Lake Islands	2005	2.K.1 The combination of Island 1 having a low elevation and the material under the island being soft, caused poor foundation conditions for the equipment resulting in equipment frequently getting stuck. A higher elevation would have displaced more of the soft substrate due to the additional weight per square foot.

Table 9.13. Lessons Learned, Design Category 3 - Island Width

Project	Year Constructed	Lesson Learned
Weaver Bottoms Pool 5	1986	3.A.1 Wider islands create more contractor flexibility when constructing the islands. These islands had a 100' top width, and 1V:4H side slopes, giving them an extremely large footprint (over 160'). This extremely large size was a benefit during construction since the contractor was able to create large containment cells on the island, into which fine sediments were hydraulically dredged and allowed to dry. These fine sediments were then spread over the island as topsoil. 3.A.2 A large top area, combined with steep side slopes, may result in gully erosion on the side slopes of the islands due to local runoff. Gullies formed on the side slopes of both Swan and Mallard island due to rainfall runoff. This was not a major problem, however some attempts were made to stabilize the gullies. This has not occurred on other island projects.
Lake Onalaska	1989	3.B.1 Berm width on these islands should have been wider than the 20 feet specified in the design. The deep water (greater than 3 foot depths) that portions of these islands were placed in resulted in excessive shoreline erosion due to the amount of sand that was transported offshore during the beach building process. In some cases almost the entire berm was eroded.
Pool 8, Phase I Stage I Horseshoe Island	1989	3.C.1 Large dredges result in islands with a large footprint. The Dredge Thompson was used to place the granular fill for this island. The dredge plume from this large dredge caused sand to spread out in the shallow backwater creating a large footprint over 150' wide in some cases.
Pool 8, Phase I Stage II Boomerang	1992	3.D.1 Berm width on these islands was 30 feet in most cases. This was adequate over 95-percent of the shorelines, however there were a couple of reaches along the main channel where the combination of wave action and river currents caused excessive erosion. Remedial stabilization was required at these sites. 3.D.2 In several reaches of Boomerang Island the berm width was reduced to 20 feet. These reaches either had shallow offshore water depths (less than 2 feet deep), protection from aquatic vegetation, protection from existing islands, or some combination of the above. The 20 foot berm was adequate at these sites.
Pool 9 Islands	1994	3.E.1 Narrow islands constructed of rock alter hydrodynamic conditions as well as earth islands but provide little terrestrial habitat and are aesthetically challenged. The Pool 9 islands had a 5 foot top width and side slopes as steep as 1V: 1.7H, resulting in a very small footprint. They reduced wave action and river currents in the project area, but have been criticized for their lack of terrestrial habitat and aesthetics.
Willow Island	1995	3.G.1 The majority of this island was stable during the 1997 and 2001 flood even though its top width was only 10'. However, a couple of small breaches did form in 1997, indicating that 10' may be approaching the lower limit for top width.

Table 9.13. Lessons Learned, Design Category 3 - Island Width

Project	Year Constructed	Lesson Learned
Pool 8, Phase II	1999	3.H.1 Berm width on these islands was 30 feet in most cases. This was adequate over 95-percent of the shorelines, however there were a couple of reaches along a large secondary channel where the combination of wave action and river currents caused excessive erosion. Remedial stabilization was required at these sites. 3.H.2 Rock sill top widths at this project were set at 13' in case a scour hole developed downstream of the rock sill. The thought was that if scour started under-mining the downstream toe, the sill would be wide enough for some self-healing to occur. However, field reconnaissance indicates that scour has not occurred at these rock sills (Photograph H.15, appendix A). The rock sill top width probably could have been 10' and perhaps even less. 3.H.3 Burrowing activities by Muskrats and subsequent collapse of the tunnels, has resulted in occasional depressions extending from the island shoreline towards the center of the island. The concern here is that a continuous tunnel through the island could create a low spot that might erode during an overtopping event. However, in all cases, these tunnels are less than 20' long so they don't create a problem in the 30' to 50' top width islands used at this project.
Polander Lake	2000	3.I.1 The majority of these islands were stable during the 2001 flood even though their top widths were only 20'. However, a couple of breaches did form, and small areas of erosion were observed, indicating that 20' may be approaching the lower limit for top width. The overall footprint of these islands was fairly typical because they had flat side slopes of 1V:5H, and berms that varied from 30 to 40 feet in width.
Spring Lake Islands	2005	3.K.1 The contractor found it difficult to maneuver equipment on island 1 because of its narrow width. Island 1 was designed with a top width of 20 feet, to reduce the size of the island footprint. A 40 foot width would have resulted in better maneuverability. 3.K.2 The downstream end of Island 4, which was in deeper water, eroded rapidly after construction due to wind-driven wave action. This was a tapered section of the island and the narrower width increased concern that a breach might form across the island. If this section had been wider, this concern wouldn't have been so great.

Table 9.14. Lessons Learned, Design Category 4 - Side Slope

Project	Year Constructed	Lessons Learned
Weaver Bottoms Pool 5	1986	4.A.1 Side slopes of 1V:4H or steeper may develop gullies if the local drainage area is large enough to produce significant runoff. Gullies formed on the side slopes of both Swan and Mallard island due to rainfall runoff. This was not a major problem, however some attempts were made to stabilize the gullies with small hand-built check dams. This problem has not occurred on other island projects. 4.A.2 Wave action quickly erodes and reshapes island shorelines, creating a beach with a flat slope (1V:8H to 1V:15H). This occurred on all of the shorelines exposed to wind fetches of a few thousand feet or more.
Lake Onalaska	1989	4.B.1 Gullies did not develop on side slopes of 1V:5H. However this may be due to the smaller local drainage area created by the 50-foot top width on the Lake Onalaska Islands compared to the 100 foot top width on the Weaver Bottoms Islands. 4.B.2 Portions of the 1V:3H riprap slopes at these islands were severely damaged when ice action pushed the toe of the rock slopes in, reshaping them to a steeper slope and leaving geotextile exposed. This was repaired by adding new rock at a flatter 1V:4H slope to cause future ice to deflect up and break rather than shoving the riprap. In addition, the greater quantity of rock that results with flatter slopes, allows for self-healing of riprap. Some rock movement has occurred with the flatter slopes, however this has not required further repair. The use of larger rock was considered, however research by the U.S. Army Corps of Engineers Cold Regions Lab (Sohdi, 1997) indicates that rock size must be 2.5 times the ice thickness to minimize the chance of movement. Since ice on Lake Onalaska reaches a thickness of 30 inches, the stone size would be exceptionally large and require special handling techniques.
Pool 8, Phase I Stage I Horseshoe Island	1989	4.C.1 Hydraulic placement of sand in shallow water results in a relatively flat slope as the dredge slurry spreads out. In one section this resulted in a significant amount of aquatic habitat being covered up. This sand was later recovered using a backhoe.
Pool 8, Phase I Stage II Boomerang	1992	4.D.1 Gradually sloping the berms results in elevation diversity and rapid colonization by woody vegetation. The top elevation of the berms varied from 632.5 to 631.0 resulting in slopes of 1V:13H to 1V:20H for the 20 and 30 foot wide berms that were used on this project. These berms were rapidly colonized by woody vegetation. 4.D.2 Wave action quickly reshapes the slope of berms, creating a beach with a flat slope (1V:8H to 1V:15H). On the long north-south leg of this island, where groins were placed, wave action quickly reshaped the berms, which had been constructed at a 1V:20H slope. This brings into question whether constructing a berm with a slope is worth the extra effort as compared to simply constructing a horizontal berm. The slope of the ends of the berms was the angle of repose for this project, however experience suggests that specifying an end slope on the berm, and subsequently defining the island footprint is better from a construction standpoint.
Pool 9 Islands	1994	4.E.1 Steep rock side slopes are stable. The design side slope of these rock islands was as steep as 1V:1.7H.
Swan Lake Illinois River	1996	4.J.1 The flat 1V:6H side slopes improved the constructability and stability of these islands, which were constructed using fine sediments.

Table 9.15. Lessons Learned, Design Category 5 - Topsoil and Vegetation

Project	Year Constructed	Lessons Learned
Weaver Bottoms Pool 5	1986	5.A.1 Beaver activity can reduce the density of woody vegetation on islands. Although, not a significant impact on island stability, beavers removed a number of trees that were growing on Swan Island. 5.A.2 High islands delay the conversion from grassy to woody vegetation. Mallard and Swan Islands are both 8-feet above the average water surface and both islands are dominated by grasses. 5.A.3 The seed mix used on high islands like Swan and Mallard is important. Swan Island, which was planted, continues to produce good growth of native grasses. Mallard Island, which had topsoil placed on it, but was not seeded, hasn't produced quality grassland habitat.
Lake Onalaska	1989	5.B.1 Supplemental fertilizing may be necessary to maintain vegetation. 5.B.2 High islands delay conversion from grassy to woody vegetation. The Lake Onalaska Islands are 6-feet above the water surface and are dominated by grass, though conversion to woody vegetation is occurring. Periodic burning may have delayed succession, however discussions with USFWS staff indicate that the fuel supply on these islands was insufficient to create a hot enough fire to kill woody vegetation.
Pool 8, Phase I Stage I Horseshoe Island	1989	5.C.1 High islands delay the conversion from grassy to woody vegetation. The west leg of Horseshoe Island is 5 to 6 feet above the average water surface and has retained its grassy vegetation longer than the East leg which was about a foot lower. 5.C.2 Sand placed for formation of the island base was left bare over the winter prior to fine placement the following spring. Significant wind driven sand erosion occurred and was deposited on ice in adjacent backwater. When the ice melted, the sand caused some loss of depth in the protected backwater. Sand should not be left bare for long periods of time without being stabilized against wind, wave or current induced erosion forces.
Pool 8, Phase I Stage II Boomerang	1992	5.D.1 Topsoil with cohesive properties provides significant erosion resistance and is a critical factor affecting island stability during overtopping floods for the first two years after construction, while terrestrial vegetation is becoming established. Boomerang and Grassy Island were stable during the 1993 flood even though the grass that was growing on the island was less than 2" tall and was still in "rows" left by the drill seeding technique when the island was overtopped. 5.D.2 A thicker layer of topsoil may promote the conversion from grasses to woody vegetation. Boomerang Island, which has up to a 48-inch layer of topsoil, quickly converted from grassy to woody vegetation. The average gradation of topsoil on this island, based on 5 samples, was as follows: 61-percent clay, 27-percent silt, and 12-percent sand. 5.D.3 The activity of birds and mammals that graze on vegetation can impact density. The density of woody vegetation on Boomerang Island was very high within 5 years of project construction, however it was greatly reduced from year 5 to 10 due to rodents girdling and killing the trees.

Table 9.15. Lessons Learned, Design Category 5 - Topsoil and Vegetation

Project	Year Constructed	Lessons Learned
Pool 8, Phase II	1999	5.H.1 Sand without a topsoil covering will erode during overtopping events. Several experimental turtle nesting mounds were included in the project. Because bare sand is needed by nesting turtles, topsoil had not been placed on the mounds. One of these mounds was completely eroded during the 2001 flood, and all suffered some erosion. Some of this erosion may also have been due to the positioning of the sand humps in line with project features designed to promote scour.
Polander Lake	2000	5.I.1 Topsoil with cohesive properties provides significant erosion resistance and is a critical factor affecting island stability during overtopping floods for the first two years after construction, while terrestrial vegetation is becoming established. The Polander Lake Islands were constructed in 2000 and were overtopped during the 2001flood before any vegetation had become established. Island erosion was minimal. 5.I.2 Based on 2004 field reconnaissance, shrub plantings were successful, with Red-osier dogwood plantings doing very well. The success of tree plantings was variable and may be a function of drought conditions that occurred the summer after planting, or perhaps was due to a less thick layer of topsoil, or both. Green ash was the most successful, with silver maple making the poorest showing. The drier conditions found on the tops of the 5 foot high islands was identified as a factor affecting tree growth. Willow is colonizing the lower portions of the islands and is beginning to encroach on areas designated as turtle nesting habitat and is crowding some of the shrub plantings. This will require some control efforts.
Swan Lake Illinois River	1996	5.J.1 Grazing by waterfowl destroyed much of the vegetation that was initially planted on the islands. Protection of the vegetation with bird netting or other techniques would have improved vegetation cover.
Peoria Lake Illinois River	1996	5.L1 Natural colonization of the island by vegetation, resulted in grass being eliminated completely from the planting plan Plantings of arrowhead, bulrush, and willow matting were also reduced. 5.L.2 Arrowhead and Bulrush plantings failed due either to high water or grazing by Grass Carp.

Table 9.16. Lessons Learned, Design Category 6 - Shoreline Stabilization

Project	Year Constructed	Lessons Learned
Weaver Bottoms Pool 5	1986	6.A.1 Islands in deep water have a high rate of shoreline erosion if they are exposed to erosive forces. The deep water these islands were placed in resulted in excessive erosion due to the amount of sand that was transported offshore during the beach building process. 6.A.2 Littoral drift (i.e. the transport of sand along a shoreline due to wave action) will occur on shorelines exposed to wave action. Groins successfully eliminated littoral drift. 6.A.3 The construction sequence delayed the application of shoreline stabilization on Swan and Mallard Islands by 2 to 4 years after construction. This resulted in some erosion, but the rock volumes were reduced because the stabilization could be placed on the shallow beach that formed. In addition, stabilization could be selectively placed on only shorelines that were eroding, resulting in less than half of the shoreline length being stabilized. 6.A.4 Shorelines exposed to more than 1 mile of wind fetch will erode. Over half of the outer shorelines of Mallard and Swan Islands eroded significantly. The shorelines in the bays, where wind fetch was typically less than 1000 feet, eroded very little. 6.A.5 Convex shorelines (e.g. island tips) eroded at a faster rate than the straight or concave shorelines. This was because the offshore beach area is larger on a convex shoreline than it is on a straight or concave shoreline. 6.A.6 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. 6.A.7 The top elevation of rock structures will decrease with time, either due to bottom displacement or ice action. The as-built elevation of the rock mound constructed along Swan Island was approximately 2 feet over the average water surface elevation. This had been reduced to 1 foot or less within about 5 years. This was not a problem since rock mound elevations only need to be near the average water surface elevation to function as wave breaks. From a lessons learned standpoint, it would have been nice to monitor this rock mound to determine its long-term effectiveness, however, the mound was raised when another rock job was being done in this area. 6.A.8 Vegetative stabilization is not adequate if the shoreline is exposed to sustained wave action throughout the year. Attempts to establish vegetation on the shorelines of Swan and Mallard Island without the benefit of rock groins were of limited success.
Lake Onalaska	1989	6.B.1 Portions of the 1V:3H riprap slopes at these islands were severely damaged when ice action displaced the rock slopes, mainly on the island tips. Using a flatter slope may have caused ice to deflect up and break rather than displacing riprap. In addition, the greater quantity of rock that usually results with flatter slopes, allows for self-healing of riprap if displacement of rock does occur. Research by the U.S. Army Corps of Engineers Cold Regions Lab indicate that rock size must be 2.5 times the typical ice thickness to minimize the chance of displacement. Since ice on Lake Onalaska reaches a thickness of 30 inches, the stone size would be exceptionally large and require special handling techniques. 6.B.2 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. 6.B.3 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.

Table 9.16. Lessons Learned, Design Category 6 - Shoreline Stabilization

Project	Year Constructed	Lessons Learned
Pool 8, Phase I Stage I Horseshoe Is	1989	6.C.1 Delaying the application of bank stabilization by one year or more may allow refinement of the overall stabilization plan, resulting in more vegetative stabilization and decreased use of rock. Less than 10-percent of this shoreline was stabilized with riprap even though over 50-percent of the shoreline is adjacent channels. Initially it was thought that riprap would be needed along the channels, however the construction sequence resulted in the sand being placed during the 1989 construction season with rock placement to be done in 1990. It was apparent by the late Spring of 1990, that only a couple of sections of the island were being exposed to erosive river currents. 6.C.2 Shallow off-shore water depths greatly reduce erosive forces. The entire backwater side of this island had off-shore water depths of less than 2 feet and extensive aquatic vegetation beds which minimized erosive forces. The woody vegetation that colonized the berm on this island provided adequate stabilization with no rock required. 6.C.3 Active sand transport in adjacent channels may aid shoreline stability. Sand transported along the island has resulted in portions of the offshore area becoming shallower since the island was constructed. 6.C.4 Placing islands a distance back from the main channel allowed for shallow water depths to dampen towboat and recreation boat waves before reaching the berm of the island, therefore reducing the need for additional bank stabilization.

Table 9.16. Lessons Learned, Design Category 6 - Shoreline Stabilization

Project	Year Constructed	Lessons Learned
Pool 8, Phase I Stage II Boomerang	1992	6.D.1 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. 6.D.2 Groins are an effective low cost means of stabilizing shorelines if wind driven wave action is the primary erosive force. Groins were not used as a means of shoreline protection until Boomerang Island was constructed in 1992. This method of protecting shorelines was so successful that groins have become the preferred method of protection in wave environments. 6.D.3 Shallow off-shore water depths greatly reduce erosive forces, even for wind fetches exceeding 2 miles. Vegetative stabilization is very effective in these situations. Over 60-percent of this island was stabilized simply by establishing vegetation on the berm (Photograph D.6, Appendix A). The backwater side of this island had off-shore water depths less than 2 feet and extensive aquatic vegetation beds which minimized erosive forces. The main channel side of this island also had shallow off-shore water depths but also benefited by having active sand transport near its shoreline. The sand has resulted in portions of this shoreline becoming even shallower, providing even more reduction in erosive forces. 6.D.4 Abrupt transitions between rock structures and the earth island may cause erosion due to eddies. Strong river currents near the large bend in this island caused erosion just upstream and downstream of the riprap protection that had been placed here. The problem was caused by eddies that formed at the abrupt transition between the reach of the island that was protected by riprap and the reach that was protected by vegetation. Remedial action was taken after the 93 flood which consisted of placing additional riprap on the upstream erosion site. This stabilized the erosion site, but created another abrupt transition, eddy, and erosion at the end of the new riprap. Eventually this problem was fixed by placing small groins in the new erosion zone. The groins gradually diminished in size in an upstream direction, eliminating the abrupt transition. 6.D.5 Littoral drift will occur on shorelines exposed to wave action. Groins successfully eliminated littoral drift. 6.D.6 Unprotected shorelines exposed to more than 1 mile of wind fetch will erode. This occurred on the long north-south leg of Boomerang Island. The water was slightly deeper here and there was not as much vegetative stabilization as the east-west leg. 6.D.7 The rock gradation is adequate to withstand wind driven wave action above the design wave. During the 1993 flood, when water surface elevations were near the top of the island, a storm event with straight-line winds exceeding 60mph occurred. Wave action generated by this event, displaced some of the smaller stones in the riprap layer, however the riprap layer remained intact. 6.D.8 Placement of islands a distance back from the main channel allowed for shallow water depths to dampen towboat and recreation boat waves before reaching the berm of the island, therefore reducing the need for additional bank stabilization.
Pool 9 Is	1994	6.E.1 Islands constructed of rock are stable; however some settling may occur.
Pool 8 Phase II	1999	6.H.1 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.
Swan Lake Illinois R.	1996	6.J.1 Unprotected shorelines will have a high rate of shoreline erosion if they are exposed to erosive forces. Because of limited project funding, the shorelines of the Swan Lake islands were left unprotected. Some of these islands have lost more than 50% of their mass due to erosion.
Peoria Lake Illinois R.	1996	6.L.1 Borrow channel overburden material that was placed near the island has functioned as a wave break, and has reduced wave action on the island shoreline. This material has remained in place and continues to protect the island.
Pool 11 Is	2004	6.N.1 Erosion protection was not initially specified, due to budget constraints. However widespread erosion required the construction of an off-shore rock mound.

Table 9.17. Lessons Learned, Constructability

Project	Year Constructed	Lesson Learned
Weaver Bottoms, Pool 5	1986	7.A.1 Displacement of existing substrate can occur, but usually doesn't have a significant affect on construction. This happened on the south side of Swan Island, and resulted in a berm being formed, which led to the inclusion of the berm design in future projects. 7.A.2 Fine sediments can be hydraulically dredged into a containment area where they can be dried out and then mixed with sand and shaped by construction equipment. The fine sediments for Mallard and Swan Island were pumped into containment cells on the islands and allowed to dry over the winter. The contractor was able to spread the fine sediment early the next construction season.
Lake Onalaska	1989	7.B.1 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 all areas and the berm elevation was exceeded by at least 0.5 feet. This could affect the growth of terrestrial vegetation on the islands, with higher islands favoring grasses. We probably would have been better off increasing the length of the island, once the material overrun was identified.
Pool 8 **Phase I** **Stage I** **Horseshoe Is**	1989	7.C.1 The dredge plume from larger hydraulic dredges, like the Dredge Thompson, with its 20-inch pipeline, results in sand being deposited over a footprint at least a 100' wide . Berming may minimize the spread of the dredge plume, however a 100' width, seems to be a reasonable footprint for larger hydraulic dredges. Horseshoe Island ended up wider than designed and in one section an effort was made to recover some of the sand and reestablish more aquatic area. 7.C.2 Fine sediments can be dried out by mechanically dredging them into a placement site where they are allowed to dry out over the winter. The fine sediments on Horseshoe Island were excavated from a wetland and allowed to dry for a year before they were placed on the island. 7.C.3 Heavy construction equipment can operate in fine sediments as thick as 2 feet without major problems. The fine sediments on Horseshoe Island were up to 2 feet thick in places during the placement of the topsoil. This caused a few operational problems, but nothing serious. 7.C.4 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 Is**	1992	7.D.1 The services of a trained plant specialist (Botanist, Forester, etc.) should be retained during final inspection to assess the success of plantings. During the inspection of this project, there was some disagreement regarding the success of the plantings on this project. This argument was settled when a person knowledgeable was able to identify the native grasses and separate them from the weeds. 7.D.2 Fine sediments must be dried out before they can be mixed with sand and shaped by construction equipment. The fine sediments on Boomerang Island were mechanically dredged and allowed to dry out over the winter. The contractor was able to spread the fine sediment early the next construction season. 7.D.3 Heavy construction equipment was able to operate in fine sediments on Boomerang Island, which were as thick as 4 feet, without major problems. 7.D.4 Islands can be constructed using fine sediments (or a mix of fines and sand). The design of Boomerang Island included a 500-foot section that included a large amount of fines. A sand base had been placed along this reach the year before. This created a construction base off of which heavy equipment could operate. Sediments excavated from the Wildcat Creek area were transported to the site by barge and placed over the sand base, and in the aquatic area behind the sand base. Side casting of fines sediments from the area adjacent the island was not used by the contractor even though this was identified as an option in the plans.

Table 9.17. Lessons Learned, Constructability

Project	Year Constructed	Lesson Learned
Pool 8, Phase II	1999	7.H.1 Excess dredge material is likely to either increase the elevation of an island or the footprint. Develop contingency plans for excess material. Island D1 (East Leg Slingshot Island) was lengthened by 50' because excess dredge material had been placed here. 7.H.2 Heavy construction equipment can operate in fine sediments as thick as 3 feet without major problems. The fine sediments on the phase II islands were up to 3 feet thick in places during the placement of the topsoil. This caused a few operational problems, but nothing serious. 7.H.3 Fine sediments must be dried out before they can be mixed with sand and shaped by construction equipment. The fine sediments on the Pool 8 Phase II Islands were pumped into a containment cell on the islands and allowed to dry over the winter. The contractor was able to spread the fine sediment early the next construction season. 7.H.4 The sand base, which consists of over 95% sand supported heavy equipment without any problems. 7.H.5 Hydraulic placement of fines on the islands caused segregation and less uniform soil gradations. The only locations this was seen as a problem was were the final gradation of material was approaching the upper limit of sand content, which influenced the establishment of terrestrial vegetation. 7.H.6 Contractor used sand from the island base to form temporary cells for the containment and dewatering of hydraulically dredged fine materials that were later incorporated with the fine material to be used as random and select fine material. This may be the most economical method of placing fines based on the fines cost comparison in Table 9.
Polander Lake	2000	7.I.1 Corps quality assurance personnel and design team members need to verify island position prior to construction. A survey error during the initial construction phase of this project resulted in dredge material being placed outside of the construction limits of this project. 7.I.2 A dewatering system for hydraulically dredged fine sediments was used at Polander Lake with partial success. Equipment problems forced the contractor to place about half of the fine sediments using mechanical dredging.
Swan Lake, Illinois River	1996	7.J.1 Use of a large (8 cubic yard) clamshell bucket improved the constructability of these islands. The larger bucket allowed the contractor to excavate larger masses of sediment preserving the cohesive strength of the sediments.
Peoria Lake, Illinois River	1996	7.L.1 Use of a large (7 cubic yard) clamshell bucket and constructing the island in 3 lifts improved the constructability of these islands. The larger bucket allowed the contractor to excavate larger masses of sediment preserving the cohesive strength of the sediments. Approximately 550,000 cubic yards of material was excavated for this project at a cost of $2/CY.
Bertom McCartney	1992	7.M.1 The embankments forming the confined disposal facility (CDF) consist of fine material within the embankment, with sand hydraulically dredged over the fine material to achieve final grade. 7.M.2 The contractor divided the CDF into two cells, providing increased retention time for improved settling characteristics.
Pool 11 Islands	2005	7.N.1 The contractor had difficulty constructing the island to the 1V:5H slope that was specified, because of the weak material that was obtained from the borrow site. 7.N.2 The fish channel is not wide enough to accommodate the crane barge forcing the contractor to over-excavate material that is not measured for payment.

9.5 Design Criteria

Tables 9.18 through 9.23 list criteria that have been developed for island design. The criteria is listed in six tables that cover six different design categories:

1. Island Layout
2. Elevation
3. Width
4. Side Slope
5. Topsoil & Vegetation
6. Shoreline Stabilization.

Each of the tables is subdivided into four design disciplines:

- Geomorphology
- Engineering
- Constructability
- Habitat

References linking the design criteria to the Physical Attribute (Appendix A), Habitat Parameter (Appendix B), Engineering Consideration (Appendix C), or lesson learned that the criteria is based on is provided. These criteria should be used as a guide for designing island projects; however, each project has its own unique characteristics that will require adjustments. The creative talents of design teams will continue to produce new innovations and new lessons learned.

Table 9.18. Design Criteria, Design Category 1 - Island Layout

Design Discipline	Design Criteria
Geomorphology	1.a Restore a riverine flow regime by rebuilding natural levees along channels. For below bankfull flow conditions, the majority of the flow conveyance should be in channels. The ratio of floodplain to channel discharge during floods should be less than 1.0. Reduce wind fetch to less than 4000 feet for average water depths of 3 feet. *Reference: Physical Attributes 1 – 5, 7; Engineering Consideration 4* 1.b Position islands to shelter adjacent shallow areas and reduce sediment resuspension. *Reference: Physical Attributes 2, 7; Engineering Consideration 4* 1.c Identify erosion and deposition zones. Position islands to increase or maintain the magnitude of erosion and deposition in their respective zones to maintain or increase bathymetric diversity. A state of dynamic equilibrium is desired where annual episodes of erosion and deposition balance each other. *Reference: Physical Attributes 1, 3, 4, 5, 7; Lessons Learned 1.B.1; Engineering Considerations 2,4* 1.d Spacing between islands and the resulting wind fetch should account for the water depth of the area that is sheltered by the island. Wind fetch should be reduced enough so that sediment resuspension for the design wind is prevented. The following table provides guidance based on calculated shear stress generated by wave action for a 20 mph wind. Water depth (feet) 1 2 3 4 Fetch (feet) 1500 3500 6000 9000 *Reference: Lessons Learned 1.H.3 Engineering Consideration 4*
Engineering	1.e Locate islands in shallow water to reduce costs and erosion potential. *Reference: Lessons Learned 1.A.2, 1.B.6, 1.C.1, 1.D.2, 1.K.1* 1f. Position islands in locations where islands existed but have eroded away to minimize displacement of existing substrate (i.e. mud-wave formation) and long-term settling. 1.g Incorporate existing island remnants into new island to reduce material quantities, shoreline erosion, and substrate displacement, and for aesthetics. *Reference: Lessons Learned 1.D.1, 1.H.1* 1.h Position perpendicular to flow and dominant wind fetch. *Reference: Lessons Learned 1.B.1, 1.B.2, 1.E.1* 1.i Initiate two-dimensional modeling early in the planning process as possible, so that results from the model can effectively be used to optimize island layout. Once an island layout is agreed to during the planning process, it is difficult to make substantive changes during later design stages because the layout decided on during planning reflects compromises by the interagency team concerning conflicting habitat goals and objectives, costs, and engineering requirements. *Reference: Lessons Learned 1.H.4*

Table 9.18. Design Criteria, Design Category 1 - Island Layout

<table>
<tr><th>Design Discipline</th><th>Design Criteria</th></tr>
<tr><td>Constructability</td><td>1.j Minimize access channel dredging, by positioning some reaches of islands close to deep water (5 feet in depth). Reference: Lessons Learned 1.D.3</td></tr>
<tr><td>Habitat</td><td>
1.k Maximize habitat area sheltered by island. Islands should be positioned to shelter the maximum amount of floodplain habitat. This includes areas that are deep (greater than 4 feet) for overwintering fish habitat and shallow (less than 3 feet) where aquatic vegetation is likely to grow. Reference: Lessons Learned 1.A.1, 1.B.1, 1.B.2, 1.B.3, 1.E.2, 1.H.3; Habitat Parameters 1,2,3; Engineering Consideration 4
1.l The following conditions should be met with regards to fish habitat. This criteria is based on research and input from State and Federal fisheries biologists.
<table>
<tr><th>Species</th><th>Velocity
(fps)</th><th>Temperature
(° C)</th><th>D.O.
(mg/L)</th><th>Depth
(feet)</th><th>Substrate</th></tr>
<tr><td>Centrarchids, winter</td><td>< .01</td><td>2-4</td><td>> 3</td><td>> 4</td><td></td></tr>
<tr><td>Centrarchids, summer</td><td></td><td></td><td>> 5</td><td></td><td></td></tr>
<tr><td>Centrarchids, spawning</td><td>< .016</td><td></td><td>> 5</td><td></td><td></td></tr>
<tr><td>Centrarchids, nursery</td><td>< .016</td><td></td><td>> 5</td><td></td><td></td></tr>
<tr><td>Lake Sturgeon</td><td>.328 - 1.31</td><td></td><td></td><td>3 – 13</td><td>silt-sand</td></tr>
<tr><td>Shovelnose Sturgeon</td><td>.65 - 1.48</td><td></td><td></td><td>13 – 25</td><td>sand</td></tr>
<tr><td>Paddlefish</td><td>< .16</td><td></td><td></td><td>13 – 25</td><td></td></tr>
</table>
Lake Sturgeon and Shovelnose Sturgeon prefer a transition zone between high velocity and low velocity, apparently adjusting their position to the most favorable conditions.
Reference: Lessons Learned 1.B.3, 1.H.2; Habitat Parameter 1
1.m Aquatic vegetation growth following island construction is a function of wind fetch, river currents, water depths, and substrate. Habitat Parameter 3 provides information on this. Reference: Lessons Learned 1.A.1, 1.B.3, 1.B.5, 1.E.2, 1.H.3; Habitat Parameter 3; Engineering Consideration 4
1.n Create multiple habitat areas with visual barriers (i.e. island with vegetation) for waterfowl resting. Reference: Habitat Parameter 2
1.o Position islands to create a littoral/riparian zone that provides loafing structure, shelter, and food along channel borders and in backwaters. In backwaters, this is to take advantage of the extremely sheltered zone immediately downwind of an island which equals 10 times the island and tree height. Reference: Physical Attribute 1; Habitat Parameter 5; Engineering Consideration 4
</td></tr>
</table>

Table 9.19. Design Criteria, Design Category 2 - Island Elevation

Design Discipline	Design Criteria
Geomorphology	2.a Islands should be constructed with a top elevation near the bankfull flood elevation to create hydrodynamic and fluvial conditions similar to those that existed for natural conditions. The bankfull flood elevation has a recurrence interval of 1.5 to 3 years. Since floodplain resistance is lower in the downstream section of the pools, an elevation slightly higher than bankfull might be needed to maintain a ratio of floodplain to channel discharge during floods less than 1, and more closely represent natural conditions. *Reference: Physical Attribute 5, 7; Engineering Consideration 3*
Engineering	2.b Islands should be stepped down in elevation in the downstream direction so that during floods overtopping of each island section progresses in a downstream to upstream direction reducing the head differential and erosion potential of the next upstream section. That rate at which the island is stepped down should be greater than the water surface slope, to ensure this downstream to upstream progression. *Reference: Lessons Learned 2.D.4,2.H.1* 2.c Rock islands or sills may replace portions of earth islands to provide floodplain flow for more frequent floods. These features should have a lower elevation than earth islands so flow first occurs over the rock reducing hydraulic forces across the earth islands during later stages of the flood. *Reference: Physical Attribute 5,7; Lessons Learned 2.E.1, 2.H.1; Engineering Considerations 2, 3* 2.d Earth berms, which are constructed on either side of the island for stabilization, should be 1 to 2 feet or above the average water surface elevation to provide optimum conditions for vegetation growth. Usually 2 feet is recommended so that there is enough sand in the berm for beach building, however a 1 foot high berm is better for Willow growth. *Reference: Lessons Learned 2.A.2, 2.B.2, 2.C.2, 2.D.4* 2.e Minimize flood impacts by choosing low elevation islands. If higher islands are included in the design, they should be aligned in an upstream/downstream orientation, so that impacts on flood elevations are minimized. If island elevations vary, the highest elevations would usually be at the upstream end of the island to mimic natural island morphology. 2.f In many reaches of the Upper Mississippi River, the sediment transport load is supply limited, resulting in relatively low sediment concentrations during floods. This means that sediment concentrations peak near the bankfull discharge and remain steady or decrease from this point on. By choosing low top elevations, the clean water that often occurs at higher discharge is conveyed over the island and through the project area, potentially scouring accumulated sediments. *Reference: Physical Attribute 5, 7; Engineering Consideration 2* 2.g Sufficient soil borings should be obtained along the island alignment so that initial and long-term settlement can be estimated. Island top elevation should be adjusted to account for settlement. *Lessons Learned 2.D.4*

Table 9.19. Design Criteria, Design Category 2 - Island Elevation

Design Discipline	Design Criteria
Constructability	2.h Construction tolerances should result in the desired final elevations and topographic variations. The term micro-topography is sometimes used and this simply means the variation in island elevation that occurs over relatively small spatial scales compared to the overall project scale. 2.i Provide at least a 3 foot base of sand for heavy equipment to operate on. In shallow water conditions, this might require that the island elevation be higher than is desired. If the existing substrate consists of sand, a base thickness less than 3 feet can be considered. Reference: *Lessons Learned 2.K.1* 2.j Excess material (i.e. if the contactor stockpiles too much material) should be incorporated in the island by increasing width or length, not elevation. *Lessons Learned 7.C.4, 2.H.4*
Habitat	2.k Design elevation should provide desired vegetation. Islands higher than 5 feet over the average water surface tend to retain their grass cover, while islands lower than 5 feet tend to convert over to herbaceous and woody vegetation. Other factors such as topsoil depth, also affect vegetation communities. *Reference: Physical Attribute 9, Lessons Learned 2.A.1, 2.A.2, 2.B.1, 2.B.2, 2.C.1, 2.C.2, 2.D.1, 2.D.3; Habitat Parameter 4* 2.l Vary island elevations from around a 2-year flood elevation to a 10-year flood elevation to provide topographic and subsequent vegetation diversity. *Reference: Physical Attribute 9, Lessons Learned 2.A.1, 2.A.2, 2.B.1, 2.B.2, 2.C.1, 2.C.2, 2.D.1, 2.D.3; Habitat Parameter 4* 2.m If the island function includes creating sheltered winter habitat for fish, the top elevation should result in infrequent overtopping during the winter months (December through February). *Reference: Habitat Parameter 1* 2.n If island function includes nesting, the top elevation should exceed the level of the 10-year flood event. *Reference: Habitat Parameter 6* 2.o On extremely sheltered shorelines, sand flats or mudflats can be constructed. The elevations of these features should be set 0.2 to 0.3 feet below the average water surface elevation that occurs during the fall migration. The micro-topography on these features is important and should result in alternating areas of habitat that are submerged or emerged by up to 0.3 feet. *Reference: Habitat Parameter 5*

Table 9.20. Design Criteria, Design Category 3 - Island Width

Design Discipline	Design Criteria
Geomorphology	3.a When it is desirable to decrease floodplain discharge during floods, use the greatest feasible width. Hydraulic slope, flow velocity, and discharge decrease with increased island width during overtopping floods so wider islands can be a factor in restoring a riverine flow regime with a floodplain to channel discharge ratio less than 1.0 during floods. *Reference: Physical Attribute 4, 5, 7*
Engineering	3.b Lower sections of island that are overtopped more frequently should be wider than higher sections. The hydraulic slope, flow velocity, and potential for erosion decreases with increased island width during overtopping floods. The range of widths used on previous projects (70 to 200 foot base width, 10 to 100 foot top width) has resulted in stable islands in almost all cases. Minor erosion and breaches have formed on islands with top widths of 10 and 20 feet, however these were easily fixed. This suggests that island width can be at the lower end of the range given above, however, the headloss across the island must be considered. *Reference: Lessons Learned 3.G.1, 3.I.1; Engineering Consideration 5* 3.c Rock sill top widths should be set at 10' to allow equipment access and to minimize seepage. However if head differentials exceed 0.5 feet, widths may have to be increased. *Reference: Lessons Learned 3.H.2* 3.d Berm width should be wide enough to provide adequate material for beach formation (the process where sand in the berm is reshaped by wave action into a gradually sloping beach) and still allow a stable 20-foot wide strip for vegetation growth. The standard berm width used on the latest projects is 40 feet, widths have varied from 20 to 60 feet. A wider vegetated berm provides better stability during floods because there is more vegetation to dissipate wave energy. It also provides a larger buffer, in case shoreline erosion is greater than expected. *Reference: Lessons Learned 3.B.1, 3.D.1, 3.D.2, 3.H.1: Engineering Consideration 6* 3.e Islands in more erosive environments should have their overall width increased to decrease the chance of breaches forming during an overtopping width. *Reference: Lessons Learned 3.K.2*
Constructability	3.f Use a minimum of a 100-foot base width when 16-inch to 24-inch hydraulic dredges are used for construction. Narrower widths will require excessive berming to contain the dredge plume. Mechanical placement of dredge material should be considered if a narrower width is desired. *Reference: Lessons Learned 3.C.1* 3.g Rock sill widths are usually set at 10' to allow equipment access over the top of the sill. However, this option is rarely used by contractors, so some flexibility to adjust rock sill width exists. 3.h The minimum working width for efficient equipment operation is 40 feet. *Reference: Lessons Learned 3.K.1*
Habitat	3.i Width may affect island function as a migratory corridor. A minimum top width of 50 feet should be used to create a forest interior for migrating birds.

Table 9.21. Design Criteria, Design Category 4 - Island Side Slopes

Design Discipline	Design Criteria
Geomorphology	4.a Wave action on shorelines with sand substrate results in erosion and subsequent formation of a beach with a slope of 1V:8H or flatter. Berms should be constructed wide enough so that after the beach has formed (through erosion of the berm) there is enough berm width left to protect the island. *Reference: Lessons Learned 4.A.2, 4.D.2*
Engineering	4.b Use side slopes of 1V:5H or flatter to reduce rill erosion due to rainfall runoff from the top of the island. *Reference: Lessons Learned 4.A.1, 4.B.1* 4.c Where riprap is being used, side slopes should be 1V:3H or steeper to reduce rock quantities. 4.d If ice forces are a problem, side slopes should be 1V:4H or flatter. *Reference: Lessons Learned 4.B.2*
Constructability	4.e An underwater side slope of 1V:3H is usually specified so that material quantities can be determined. However, attempting to construct the underwater portion of the island is difficult to do and inspect. The bottom line is to provide enough material in the island berm so that erosive forces (wave action, river currents, ice) can form the underwater portion of the island (i.e. the beach). *Reference: Lessons Learned 4.D.2* 4.f A flatter side slope improves the constructability of islands that are constructed using fine sediments. *Reference: Lessons Learned 4.J.1*
Habitat	4.g Flatter slopes provide better habitat for shore birds, wading birds, nesting turtles, and a variety of other species. However, a flat slope near the average annual water level will be quickly colonized with woody vegetation, which may eliminate bird habitat and create a barrier to nesting turtles. Side slopes are usually not based on habitat. *Reference: Lessons Learned 2.A.2, 2.C.2, 2.D.3, 4.D.1; Habitat Parameters 4, 5, 6*

Table 9.22. Design Criteria, Design Category 5 - Topsoil and Vegetation on Islands

Design Discipline	Design Criteria
Geomorphology	5.a Topsoil thickness affects the vegetation communities and subsequently the hydraulic roughness of the island. Thicker topsoil layers will result in more woody vegetation creating a rougher surface during the annual flood, which usually occurs during the dormant season. This will reduce flow over the island and increase the potential for sediment deposition on the island.
Engineering	5.b A topsoil thickness of 12 inches is recommended to provide adequate coverage throughout the island. *Reference: Lessons Learned 5.D.1, 5.D.2, 5.H.1, 5.I.1; Habitat Parameter 4* 5.c Topsoil should consist of at least 40-percent fines (i.e. 40-percent of material passes 200 sieve), but not more than 70-percent fines. Coarse material is needed for infiltration. Anfang and Wege found that sites with more than 35-percent fines had a higher percent cover than sites with lesser amounts. *Reference: Lessons Learned5.D.2; Habitat Parameter 4* 5.d Topsoil placement should occur during the same construction season as granular fill placement to minimize the chance of erosion during Spring floods. The cohesive properties of topsoil helps to stabilize islands during overtopping events. This is especially important since Anfang and Wege found that it may take several (three to six) growing seasons before vegetation reaches a desired/maximum density. *Reference: Lessons Learned 5.D.1, 5.H.1, 5.I.1*
Constructability	5.e Fine sediments must be dried before construction equipment can be used to spread the material. *Reference Lessons Learned: 7.A.2 7.C.2, 7.D.2, 7.H.3* 5.f Use a maximum of 8-inches of fine sediment when disking with standard farm equipment. *Reference: Habitat Parameter 4* 5.g The thickest layer of topsoil that has been placed with standard construction equipment is 4 feet - this is about the upper limit for constructability. *Reference: Lessons Learned 7.C.3, 7.D.3, 7.H.2* 5.h Topsoil and sand should be placed during the same construction season to minimize loss of sand due to wind or floods. *Lessons Learned 5.D.1, 5.I.1*
Habitat	5.i Topsoil thickness depends on the types of vegetation desired. To maintain grasses and delay the conversion to woody vegetation, a thinner layer of topsoil should be placed on higher elevation sites. This prolongs the time that the island provides optimal conditions for ducks and other birds that use grass. The following table provides some guidance on topsoil thicknesses. Vegetation Type — Topsoil Thickness Shrubs , Trees & Herbaceous — 12” or greater Grasses — 6” to 12” *Reference: Lessons Learned 5.A.2, 5.B.2, 5.C.1, 5.D.2; Habitat Parameter 4, 6* 5.j Diverse, and thus more expensive native prairie seed mixes should not be used on lower sections of islands that will be frequently overtopped. In addition to competition with invasive species transported in by the river, woody vegetation will quickly become a problem. Once an island is overtopped, the planted seed mix is often overtaken by seeds carried by the river. Switchgrass seems to be one of the most aggressive and successful species and should be planted sparingly at sites where a diverse mix of grasses and forbs is desired. The seed mix should also include a legume species to replenish soil nitrogen levels to improve long term performance of plantings. 5.k Consider techniques to discourage grazing of new plants during the first few years after construction. Reference: *Lessons Learned 5.J.1*

Table 9.23. Design Criteria, Design Category 6 - Island Shoreline Stabilization

Design Discipline	Design Criteria
Geomorphology	6.a Stabilize island shorelines when the combination of river currents, waves, or ice remove substrate from a reach of shoreline faster than it is transported in. *Reference: Physical Attribute 5* 6.b Rock or wood structures must be constructed along shorelines subject to wave action from wind fetches greater than 1-mile. Vegetation by itself will not stabilize a shoreline or embankment subject to sustained long-term wave action. *Reference: Lessons Learned 6.A.8, 6.B.3* 6.c Create dynamic shorelines with a transition from aquatic habitat to beach habitat to terrestrial vegetation. If the shoreline is completely stable, terrestrial vegetation will encroach into the beach zone. *Reference: Lesson Learned 6.D.1*
Hydraulic/ Sediment Engineering	6.d Use tables 4, 7, 9, 10, and figure 4; Engineering Consideration 1 (Appendix C), and the Shore Protection Manual to design shoreline protection. Some rules of thumb include: - The potential for shoreline erosion increases with water depth. Shorelines with offshore water depths less than 2 feet can be stabilized with vegetation. Those with offshore depths greater than 3 feet usually need rock structures. *Reference: Lessons Learned 6.A.1, 6.B.2, 6.C.2, 6.D.3;* ***Engineering Consideration 1*** - Extremely sheltered shorelines (those exposed to less than a 2000 foot wind fetch) should be stabilized with vegetation only. *Reference: Lessons Learned 6.A.4; Engineering Consideration 1* - The elevation on rock structures decreases with time due to settlement or ice action. This should be taken into consideration in feature design and in the soil boring plan. *Reference: Lessons Learned 6.A.7, 6.E.1* 6.e On shorelines where wave action is the dominant erosive force, biotechnical stabilization should be used. This involves construction of an earth berm, at an elevation 2 feet or less above the average water surface, where woody vegetation will grow. The berm must be wide enough so that even if woody vegetation density is not high, there is sufficient energy dissipation to protect the main portion of the island during high water. In most cases, after the berm is constructed, erosion of the outer portion of the berm due to wave action results in offshore transport of sand, which forms a gradually sloping beach with a 1V:8H to 1V:12H slope. The goal is to construct a wide enough berm so that after the beach building process is complete, at least 20-feet of berm remains as substrate for woody vegetation growth. Although berms as narrow as 20 feet have been used where minimal erosion was expected, 40 feet is the standard berm width. Structural measures such as groins or offshore mounds may be needed to minimize berm erosion. Rock groins are constructed perpendicular to the berm to prevent longshore transport of sand. Offshore rock mounds can be used instead of groins to add diversity to an island shoreline. Willows are planted near the back of the berm for stabilization purposes. *Reference: Lessons Learned 6.D.1, 6.D.2; Engineering Consideration 1* 6.f On shorelines where river currents are the dominant erosive force, the same design as described above in 6e. is used except that vanes are used instead of groins. Vanes are 30 to 50 feet long, have a 3 foot top width, 1V:1.5 H side slopes and are spaced a distance equal to 4 times the vane length. Vanes are angled upstream 30 to 45 degrees with the shoreline and decrease in elevation from the bankfull elevation at the shoreline to 1 foot below the average water surface at the riverward end. *Reference: Engineering Consideration 1* 6.g A swath of woody plants at least 20 feet wide is needed to provide rigid stems and protect the shoreline during the spring flood season. *Reference: Lessons Learned 6.D.1, 6.D.3; Engineering Consideration 1* 6.h If ice action is severe, flatten rock slopes to 1V:4H or flatter. *Reference: Lessons Learned 6.B.1; Engineering Consideration 1*
Constructability	6.i Provide access to the site for trucks or barges hauling rock.
Habitat	6.j Create diverse shoreline habitat with littoral/riparian area that includes aquatic, beach, and terrestrial zones. 6.k Build sand flats and mud flats near islands in sheltered areas. 6.l Use larger stone size than required to provide better substrate for benthic organisms and fish. *Reference: Habitat Parameter 1* 6.m Include woody material (logs, stumps) in shoreline protection to provide loafing structure and shelter. Consider optimal wood types based on decay resistance and weight (heavier generally being better) *Reference: Habitat Parameter 2, 5; Engineering Consideration 7*

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UPPER MISSISSIPPI RIVER SYSTEM
ENVIRONMENTAL MANAGEMENT PROGRAM
DESIGN HANDBOOK

CHAPTER 9

ISLANDS

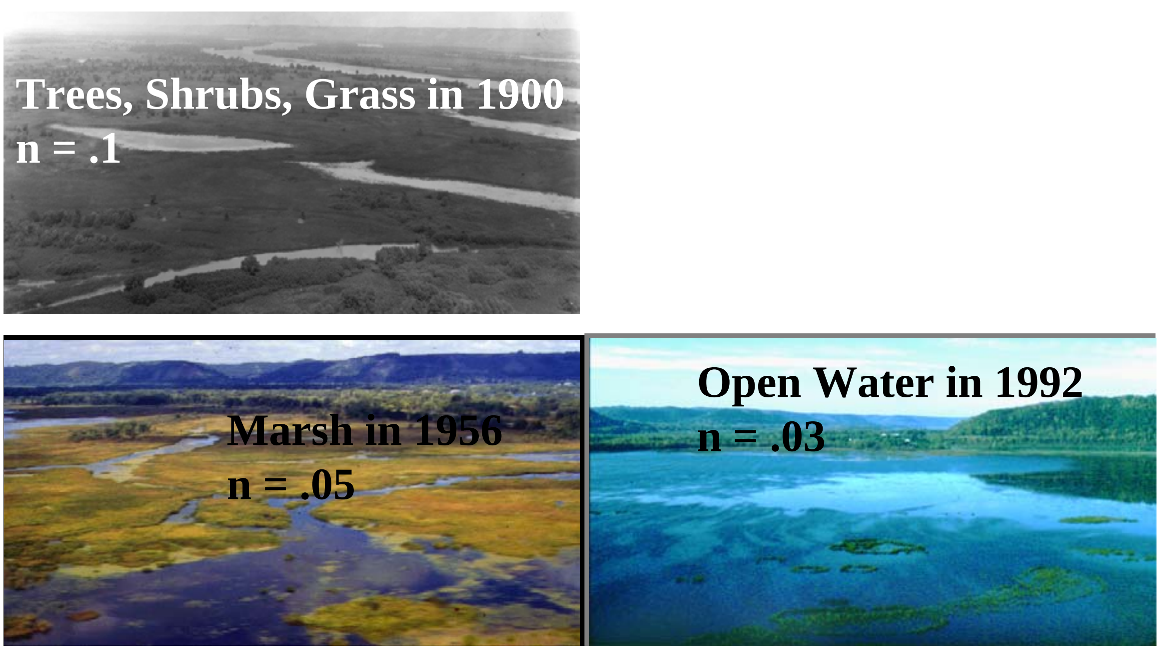
APPENDIX A
PHYSICAL RIVER ATTRIBUTES

Effects of Lock and Dams and Islands on
Hydraulics, Sediment Transport, and Geomorphology

APPENDIX A
PHYSICAL RIVER ATTRIBUTES

The Upper Mississippi River is island braided with many anastamosing 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 the natural condition of the river (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 and most restoration efforts attempt to alter the impacts of the locks and dams.

Construction of the locks and dams submerged the natural levees and floodplain creating navigation pools upstream of the dams and leaving only the higher parts of the natural levees as islands. Table 9.A.1 shows the effect of submergence on parameters describing hydrodynamics, sediment transport, and geomorphology in the lower portions of navigation pools. Submergence altered habitat in the floodplain producing a robust response of aquatic plants and animals in the shallow marshes that were created. However, because a minimum pool level is maintained for navigation, the low water portion of the annual hydrologic cycle was eliminated ($\Delta \mathbf{z_w}$ decreased). This degraded habitat for many plants and animals adapted to a larger range of water level fluctuations. The shift in vegetation communities (photograph 9.A.1) decreased floodplain resistance causing increased floodplain conveyance (i.e. floodplain connectivity) with time (Q_f/Q_t increased, Qc/Q_t decreased).



Photograph 9.A.1. Weaver Bottoms, Pool 5 - Changes in Floodplain Vegetation and Roughness

For river flows near and well above bankfull, the majority of the conveyance is now in the floodplain in the lower reaches of the navigation pools. This increased the delivery of sediment to the floodplain (D_f increased). Chen and Simons, 1979, found that the water surface for a given flood discharge in the upper and middle reaches of the navigation pools was decreased after the locks and dams were constructed (Δz_w decreased). They attributed this to the destruction of overbank vegetation, which increases the riverbed area (the flow carrying portion of the river). A comparison of water surface profiles for pre- and post-lock and dam conditions indicates that the decrease in water surface elevation was as much as 1-foot in the upper portions of the pool. Combined with the increase in water surface in the lower reaches of the pools, caused by the dams, the hydraulic slope in the pools for flood conditions as been decreased as much as 20-percent. Channel velocities (v_c) decreased and the lower reach of the navigation pools became more depositional (Qs decreased). Sediment deposition in the main channel (D_c) was increased adjacent secondary channels where flow enters the floodplain, requiring periodic dredging to maintain the 9-foot navigation channel. The combination of dredging and sediment flow to the floodplain through the secondary channels limits the supply of sand-size sediment to the lower portions of the navigation pools, which is a potential factor increasing shoreline erosion (E_b increased). Superimposed on this lower velocity depositional system is a high velocity reach at each lock and dam, which presents a potential barrier to migrating fish. Although a significant quantity of backwater habitat was initially created by submergence, island erosion and the continued increase in floodplain conveyance has increased velocities (v_f) in many of these areas making them less suitable for plants and animals. The width of the main channel (W_c) increased in the lower reaches of the pools due to Lock and Dam construction (Chen & Simons 1979, WEST Consultants 2000, Collins & Knox 2003).

Wind driven wave action has become a more significant factor in the floodplain affecting both the transport of sediment and morphological changes in the floodplain. Many of the islands and shallow areas in the lower pools eroded (E_f, E_b increased) due to wave action (WEST Consultants, 2000) (photograph 9.A.2) . Sediment transport in the floodplain now is affected by daily wind conditions as much as seasonal variations due to annual cycles of basin-wide runoff. This has resulted in increased suspended sediment concentrations (SS).

Photograph 9.A.2. Pool 8, Phase II, Stoddard Bay. Erosion, due primarily to wind driven wave action, reduced over one mile of barrier islands to this one remnant by 1995.

While project goals and objectives usually focus directly on the improvement of habitat in the floodplain, the physical impact of island construction is to partially restore riverine hydrodynamic, sediment transport, and geomorphic conditions. As Table 9.A.1 illustrates, islands reverse many of the effects of lock and dam construction. A new island essentially becomes the new natural levee, separating channel from floodplain, reducing channel-floodplain connectivity, and increasing channel flow while decreasing the amount of floodplain flow (Q_c/Q_t increases, Q_f/Q_t decreases). This increases the velocity in adjacent channels increasing the erosion and transport of sediment (v_c, E_c, increased). Wind fetch and wave action is reduced in the vicinity of islands, reducing the resuspension of bottom sediments, floodplain erosion, and shoreline erosion (***F***, ***SS***, E_f, E_b decreases). In some cases, islands act primarily as wave barriers and don't alter the river-wide distribution of flow. Islands reduce the supply of sediment to the floodplain potentially decreasing floodplain sediment deposition (D_f). Constructing islands (or natural levees) is a necessary step in restoring the form, function, and habitat value in the lower portions of the navigation pools.

The natural resource managers and scientists involved in the Habitat Needs Assessment (Theiling et al. 2000) indicated that the future river should be characterized by: improved habitat quality, habitat diversity, and a closer approximation of pre-development hydrologic variability. In fact, the subject of restoring natural conditions is frequently discussed at all levels of planning and design. However, the relationships between the flow of water, the transport of sediment, and the biota in a natural system are not always well defined. Habitat goals are developed first and then the physical conditions that will most likely achieve those goals are determined. While this will continue to be the case, HREP design teams will benefit if the physical condition of the natural river is defined. The Pool 8 Islands, Phase III project was the first to incorporate processes as an objective.

In table 9.A.2, the first column lists river attributes as defined by McBain and Trush (1997). These attributes describe the fluvial geomorphic processes that sustain ecosystem integrity. They were developed for cobble and gravel-bedded rivers in the Western United States, however they apply, with some modification, to the Upper Mississippi River (column 2). All of these attributes describe the relationship between the hydrologic regime and sediment transport, and the resulting geomorphic and biologic condition of a river. Restoring these attributes on a river reach will help achieve the broad goals stated in the habitat needs assessment of improved habitat quality and diversity, and more natural hydrology. These attributes along with habitat parameters, engineering considerations, and lessons learned, form the basis for design criteria and project design once goals and objectives are defined.

Table 9.A.1. Effects of Lock and Dams and Island on Parameters Describing Hydrodynamic, Sediment Transport, and Geomorphic Regimes in the Lower Reaches of Pools in Pools 1 Through 13 of the UMRS

Parameter	**Definition**	**Lock and Dam Effects in Lower Reaches of Pools**	**Island Effects**
Q_c	Channel discharge including secondary channels	- [1]	+ [2]
Q_f	Floodplain discharge	+	-
Q_t	Total river discharge		
Q_c/Q_t	Ratio of channel discharge to total discharge	-	+
Q_f/Q_t	Ratio of floodplain discharge to total discharge	+	-
v_c	Channel velocity	-	+
v_f	Floodplain velocity	+	-
W_c	Channel width including secondary channels	+	-
z_c	Channel elevation	+	-
z_f	Floodplain elevation	+, -	+, -
Δz_w	Difference in elevation between the two-year flood and low flow	-	
F	Wind fetch in floodplain	+	-
Q_s	Sediment load	-	+
SS	Suspended sediment concentration	+	-
D_c	Sediment deposition rate in channels	+, -	-
D_f	Sediment deposition Rate in floodplains	+	-
E_c	Channel bed erosion rate	-	+
E_b	Bankline erosion rate	+	-
E_f	Floodplain erosion rate	+	-
d_{50}	Sediment particle size in channels	-	+

[1] + indicates that magnitude of parameter increased
[2] - indicates that magnitude of parameter decreased

Table 9.A.2. Attributes of Alluvial River Ecosystems and the Condition of Those Attributes for the Lower Reaches of Pools on the UMR, Pools 1-10

General Attributes of Alluvial River Ecosystems from McBain. and Trush (1997)	Condition of Attribute in the Lower Reaches of Pools on the UMR, Pools 1-10
Attribute No. 1. Spatially complex channel morphology. No single segment of the channel bed provides habitat for all species, but the sum of channel segments provides high-quality habitat for native species. A wide range of structurally complex physical environments supports diverse and productive biological communities	Submergence of the natural levees and floodplain and subsequent island erosion has decreased main channel flow and velocity creating a more depositional condition. Dredging and sediment deposition in the middle reaches of pools limits the amount of coarse sediment transported to the lower reaches. The increased fine and course sediment transport to the backwater areas occurs at most times during the year, compared to being flood event driven prior to impoundment. With the limited supply of coarse sediment, the lower reaches of pools have remained fairly deep through time. However, there has be a simplification of the bathymetry in these lower sections of the pools as wave action erodes "high" spots and sedimentation fills in the historic floodplain depressions that are now permanently inundated (see pool 13 bathymetric comparison by USGS and the pre and post bathymetric analysis for Phase II). These factors limit the formation of complex morphological features such as point bars, longitudinal bars, and riffles with coarser sediments. The minimum water surface elevation that is maintained for navigation usually submerges sand bars that form. Wing dams create flow and substrate diversity in some reaches.
Attribute No. 2. Flows and water quality are predictably variable. Inter-annual and seasonal flow regimes are broadly predictable, but specific flow magnitudes, timing, durations, and frequencies are unpredictable due to runoff patterns produced by storms and droughts. Seasonal water quality characteristics, especially water temperature, turbidity, and suspended sediment concentrations, are similar to regional unregulated rivers and fluctuate seasonally. This temporal " predictable unpredictability" is the foundation for river ecosystem integrity.	Variability occurs at frequencies associated with inter-annual, seasonal, and storm event time scales. However wind-driven wave action causes daily and diurnal changes in water quality, especially turbidity and suspended sediment concentration in the lower reaches of pools. The increased turbidity reduces light penetration decreasing the growth of aquatic plants and affects other aquatic organisms.
Attribute No. 3. Frequently mobilized channelbed surface. Channelbed framework particles of coarse alluvial surfaces are mobilized by the bankfull discharge, which on average occurs every 1-2 years.	Channelbed sediments consist of sands that are mobilized by discharges much lower than the bankfull discharge. Measurements in lower pool 8 by personnel from ERDC indicated significant bed load movement for a discharge of 50,000 cfs, which is about 60-percent of the bankfull discharge (Abraham et al. 2003). However, due to submergence of the floodplain and island erosion, floodplain conveyance in the lower reaches of navigation pools exceeds 50-percent of the total river discharge at the bankfull flow condition. Flow velocities and the potential to mobilize and transport sand-size sediments are decreased because of this. Normally this would result in rapid aggradation of the channel bed, but dredging and floodplain deposition in the middle reaches of navigation pools limits the supply of coarse sediments. Sand that enters the floodplain deposits in deltas, on natural levees, and in other features with little chance for remobilization.
Attribute No. 4. Periodic channelbed scour and fill. Alternate bars are scoured deeper than their coarse surface layers by floods exceeding 3- to 5- year annual maximum flood recurrences. This scour is typically accompanied by re-deposition, such that net change in channelbed topography following a scouring flood usually is minimal.	The UMR is a sand-bed river and so there generally is not an armor layer that is scoured. Because of submergence and island erosion, the floodplain conveyance in the lower reaches of navigation pools is high and velocities for the 3 to 5 year floods are not significantly greater than those for the bankfull discharge.

Table 9.A.2. Attributes of Alluvial River Ecosystems and the Condition of Those Attributes for the Lower Reaches of Pools on the UMR, Pools 1-10

General Attributes of Alluvial River Ecosystems from McBain. and Trush (1997)	**Condition of Attribute in the Lower Reaches of Pools on the UMR, Pools 1-10**
Attribute No. 5. Balanced fine and coarse sediment budgets. River reaches export fine and coarse sediment at rates approximately equal to sediment inputs. The amount and mode of sediment storage within a given river reach fluctuate, but also sustain channel morphology in dynamic quasi-equilibrium when averaged over many years. A balanced coarse sediment budget implies bedload continuity; most particle sizes of the channelbed must be transported through the river reach	A bed material (ie. coarse material) sediment budget developed for the St. Paul District reach of the UMR (Hendrickson, 2003) indicates a decrease in the sediment load from the upper to the lower reach of the navigation pools. The only exception to this is where tributaries entered and caused a spike in the sediment load. This decrease is due to hydrodynamic changes and dredging. Main Channel conveyance changes from 80-percent of the total river discharge in the upper reaches of the navigation pools to less than 50-percent of the total river discharge in the lower reaches at the bankfull flow condition. As flow leaves the channel and enters the floodplain it carries coarse sediment, which is trapped in deltas or on the natural levees. Channel velocities and the potential to mobilize and transport sand-size sediments is decreased as the amount of main channel flow decreases, leading to coarse sediment deposition in channels and the floodplain. The lack of a balanced coarse sediment budget leads to dredging in the navigation channel, which reduces the bed material load to a level that the lower reaches can transport. Sediment budget studies in Pool 13 (Gaugush, 1997), Weaver Bottoms in Pool 5 (Nelson et al., 1998), and Peterson Lake in Pool 4 (Unpublished St. Paul District Data, 1995) indicate a balance between fine sediment input and output. However, transect measurements in Pools 4, 8, and 13 indicate a net accumulation of sediments and a gradual increase in the bed elevation of backwater areas (Rogala, 2003). Also, Collins and Knox (2003) found net accumulation of fine and coarse sediments on natural levees in pool 10. These were areas that are only inundated during floods. It is probable that the Upper Mississippi River traps more of the fine sediment load than it exports, however there certainly are reaches where there may be some type of quasi-equilibrium.
Attribute No. 6. Periodic channel migration. The channel migrates at variable rates and establishes meander wavelengths consistent with regional rivers having similar flow regimes, valley slopes, confinement, sediment supply, and sediment caliber.	Most geomorphic studies of the UMR indicate a relatively stable main channel through time. Knox (2002), using radiocarbon dating of deep cores representing floodplain sites in Pools 9 and 10, found long term stability of major island and floodplain landforms. Exceptions to this stability occurred where large tributaries enter the main channel, supplying a large amount of coarse sediment. Archaeological studies of the Mississippi floodplain in Pool 10 have found campsites and artifacts, dating back 1300 to 2000 years, buried on lateral accretion deposits adjacent present day channels. This evidence suggests that channel position has changed little in the last 2,000 years (Stoltman et al. 1982, Church 1985). Additional archaeological data provides evidence that the position of some landforms within the valley have not changed in 8,000 years Development of the UMR for navigation, aimed to stabilize the main channel even more. Chen and Simons (1979), using a combination of river surveys and aerial photographs, found that the position of the river did not change appreciably in lower pool 4 with the construction of training structures and locks and dams. However, a recent study indicates that in some areas secondary channels may have been much more dynamic, at least since the locks and dams were constructed. Carson (unpublished thesis 2004) found significant migration and expansion of secondary channels at his study sites in the Goose Island backwater in the middle reach of pool 8. Secondary channels in the middle reaches typically have hydraulic slopes higher than .0001. This is because there is often a significant water surface differential between backwaters, which might have their main connection with the river miles downstream, and the adjacent main channel. Additional factors contributing to these mid-pool dynamics induced by impoundment may also include changes in vegetation coverage (from forest to grasses) that reduced floodplain roughness, alteration of the floodplain for urban development upstream of this location and island dissection. In the lower reaches of pools, the submergence of natural levees and the floodplain has decreased the hydraulic slope to .0001 or less and current velocities in secondary channels are well below the threshold for major channel migration.

Table 9.A.2. Attributes of Alluvial River Ecosystems and the Condition of Those Attributes for the Lower Reaches of Pools on the UMR, Pools 1-10

<table>
<tr><th>General Attributes of Alluvial River Ecosystems from McBain. and Trush (1997)</th><th>Condition of Attribute in the Lower Reaches of Pools on the UMR, Pools 1-10</th></tr>
<tr><td>Attribute No. 7. A functional floodplain. On average, floodplains are inundated once annually by high flows equaling or exceeding bankfull stage. Lower terraces are inundated by less frequent floods, with their expected inundation frequencies dependent on norms exhibited by similar, but unregulated river channels. These floods also deposit finer sediment onto the floodplain and low terrace.</td><td>The floodplain and natural levees in the lower reaches of navigation pools were permanently submerged by Lock and Dam construction. Subsequent island erosion (i.e. natural levee erosion) and a shift in vegetation communities, which decreased floodplain resistance, resulted in a trend of increasing floodplain conveyance and decreased channel conveyance with time. Channel-floodplain connectivity, whether measured in terms of number of connections or the amount of water conveyed in the floodplain increased. In many pools this trend continues today as islands erode and secondary channels get wider. One of the impacts of this is degraded conditions for backwater fish. Measurements at secondary channels in Pool 7 in 1980 (Pavlou et al., 1982) and in 1991 (Hendrickson et al., 1994) indicated a 10-percent increase in the amount of water conveyed through Lake Onalaska. For river flows below bankfull, 20 to 70-percent of the total river flow is conveyed in the floodplain in the lower reaches of pools. For flood conditions, floodplain conveyance is even higher (see table below). This increases the delivery of sediment to the floodplain causing sediment deposition. In the submerged lower reaches of navigation pools, velocities often are too high to provide sheltered habitat to fish and other organisms.

Percent of the Total River Discharge Conveyed in the Floodplain in the Lower Reach of Navigation Pools Where Islands Have Been Constructed for Below Bankfull and Flood Conditions

<table>
<tr><th>Pool</th><th>River Mile</th><th>Below Bankfull</th><th>Flood</th></tr>
<tr><td>5</td><td>744</td><td>58</td><td>72</td></tr>
<tr><td>5A</td><td>730</td><td>27</td><td>46</td></tr>
<tr><td>7</td><td>704</td><td>62</td><td>74</td></tr>
<tr><td>8</td><td>687</td><td>73</td><td>88</td></tr>
<tr><td>9</td><td>656</td><td>52</td><td>-</td></tr>
</table>

Sediment transport in the floodplain now is affected by daily wind-driven wave action as much as seasonal variations due to annual cycles of basin-wide runoff. The bottom shear stress generated by waves exceeds the critical shear stress for sediment resuspension in shallow backwater areas. This can result in daily spikes in suspended sediment concentrations (SS) to levels that can be several times greater than background levels. Fine sediment export from backwaters occurs throughout the year due to wave action.

The processes of sediment deposition in deeper permanently submerged areas of the floodplain and erosion of islands due to wave action in the pools has decreased the bathymetric complexity and habitat diversity in these areas.</td></tr>
</table>

Table 9.A.2. Attributes of Alluvial River Ecosystems and the Condition of Those Attributes for the Lower Reaches of Pools on the UMR, Pools 1-10

<table>
<tr><th>General Attributes of Alluvial River Ecosystems from McBain. and Trush (1997)</th><th>Condition of Attribute in the Lower Reaches of Pools on the UMR, Pools 1-10</th></tr>
<tr><td>Attribute No. 8. Infrequent channel resetting floods. Single large floods (e.g. exceeding 10-yr to 20-yr recurrences) cause channel avulsions, rejuvenation of mature riparian stands to early-successional stages, side channel formation and maintenance, and create off-channel wetlands (e.g., oxbows). Resetting floods are as critical for creating and maintaining channel complexity as lesser magnitude floods.</td><td>Most geomorphic studies of the Upper Mississippi River indicate a relatively stable main channel through geologic time.

In the lower reaches of pools, the submergence of natural levees and the floodplain has decreased the hydraulic slope to .0001 or less and current velocities in secondary channels are well below the threshold for major channel migration. Wind driven wave action eroded many of the natural levees (i.e. islands) decreasing channel velocity even more. Sand that does enter the floodplain, deposits and forms deltas with little chance for remobilization. In a few locations, coarse sediment transport has resulted in the formation of emerged sand deposits following recent floods. These deposits are colonized by terrestrial vegetation and become semi-permanent land features in the lower pools. While this process is encouraging, it is extremely small scale, and even if the rate of deposition increased, two questions remain. First, will on-going depositional processes occur at an adequate rate to replace desirable floodplain habitat lost over the last 70 years? Second, will the quality of the terrestrial habitat on these low elevation features, be of equal value to the higher elevation features that are eroded? The answer to both of these is probably no, and so construction of artificial islands is necessary to achieve the goals and objectives that have been set for the UMRS.

Sediment deposits in deltas and sand bars are colonized by woody vegetation representing early successional stages of forest development.</td></tr>
<tr><td>Attribute No. 9. Self-sustaining diverse riparian plant communities. Natural woody riparian plant establishment and mortality, based on species life history strategies, culminate in early and late successional stand structures and species diversities (canopy and understory) characteristics of self-sustaining riparian communities common to regional unregulated river corridors.</td><td>Water surface elevations in the lower reaches of pools are maintained at a high and very stable elevation. There is very little difference between low flow conditions and flood conditions, and in some cases the water surface actually drops due to the operation of the Locks and Dams (see table below). Because of this, species diversity has decreased with time. Non-native Canary grass and mono-cultures of silver maple are the dominant species on many of the remaining landforms.

Water Surface Elevations for Low Flow and Bankfull Flow Conditions at Lock and Dams 4 Through 10.

<table>
<tr><th>Pool</th><th>Low Flow
Water Surface
75% Exceedance</th><th>Bankfull Flow
Water Surface
1.5 yr flood</th><th>Difference
(feet)</th></tr>
<tr><td>4</td><td>667.0</td><td>666.5</td><td>-.5</td></tr>
<tr><td>5</td><td>659.8</td><td>659.5</td><td>-.3</td></tr>
<tr><td>5A</td><td>650.8</td><td>650.8</td><td>0</td></tr>
<tr><td>6</td><td>645.4</td><td>644.5</td><td>-.9</td></tr>
<tr><td>7</td><td>639.0</td><td>639.0</td><td>0</td></tr>
<tr><td>8</td><td>630.7</td><td>630.0</td><td>-.7</td></tr>
<tr><td>9</td><td>619.5</td><td>620.0</td><td>.5</td></tr>
<tr><td>10</td><td>611.0</td><td>612.6</td><td>1.6</td></tr>
</table></td></tr>
<tr><td>Attribute No. 10. Naturally fluctuating groundwater table. Inter-annual and seasonal groundwater fluctuations in floodplains, terraces, sloughs, and adjacent wetlands occur similarly to regional unregulated river corridors.</td><td>Water surface elevations in the lower reaches of pools are maintained at high and stable elevation (see table above). This has elevated the groundwater table in these reaches.</td></tr>
</table>

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CHAPTER 9

ISLANDS

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HABITAT PARAMETERS

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Habitat projects alter the physical condition of the river to attain a biologic response that achieves a habitat goal. Project monitoring to determine if goals and objectives were met has provided some information regarding cause and effect relationships, however given the complexities of the Upper Mississippi River, much uncertainty remains. Development of a GIS data base like that used for the habitat needs assessment (Thieling, 2000) allows delineation of land cover and the species likely to occur in an area. This same data could be used to develop biological models that predict the habitat response based on physical parameters like water depth, current velocity, substrate, and wind fetch. In the future, models such as these could be used during the planning and design of island projects to evaluate biological benefits.

The natural river paradigm, which states that restoration to natural conditions provides the best habitat for the native species, should be considered also. However, this requires information regarding the condition of the natural river, which often doesn't exist, and ignores the fact that the altered river provides valuable habitat for many species. One consistent theme between habitat objectives for island projects and the natural river paradigm is the recognition that floodplains should convey water during floods, but for low flow conditions, water should be conveyed in channels with minimal floodplain flow. Figure 9.B.1 illustrates how this has been accomplished in Pool 8 by constructing islands.

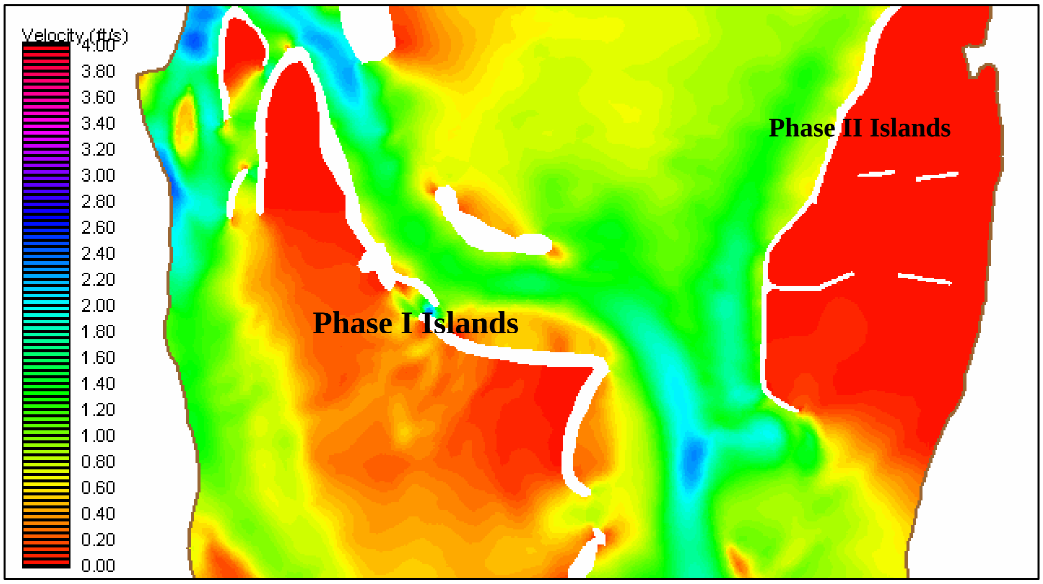

Figure 9.B.1. Current Velocity in the Pool 8, Phase I and II Areas Based on Two Dimensional Modeling Red indicates low velocity floodplain areas created by the islands during non-flood conditions.

Regardless of the tools available to HREP design teams, the most critical factor in island design is to have well-articulated habitat objectives and habitat parameters that lead to the final design and ultimately to a constructed island that meets the objectives. The spatial scale these objectives and parameters cover might include the entire project area (e.g. creating specific physical and water quality conditions in the project area for backwater fish) or they may be focused on specific components of the project (e.g. the design of loafing structures associated with shoreline stabilization).

The following is a list of habitat parameters that have been established for island projects to meet habitat objectives. The Fish and Wildlife Work Group (FWWG) provided most of this information. 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.

Habitat Parameter 1. Fish Habitat. Table 9.B.1 lists the physical conditions that have been established for various species of fish. The conditions listed for Centrarchids (bluegills, bass, crappies) were established for the Pool 8, Phase II island project. This resulted in increased fish populations in Stoddard Bay (WDNR data). The objective was to create 200 acres of over-wintering habitat between the months of November and March. Island and rock sill elevations were set high enough so that overtopping during these months would occur less than once in ten years, while at the same time minimizing the number and duration of overtopping events during the remainder of the year. The depth criteria of over 4 feet provides optimum conditions, however surveys indicate that Centrarchids will use shallower depths if ice thicknesses are not too great. Groundwater inflows can have an effect on winter habitat, however data does not exist to quantify this impact.

Table 9.B.1. Physical Conditions for Fish Habitat

Species	Velocity (fps)	Temperature (° C)	D. O. (mg/L)	Depth (feet)	Substrate
Centrarchids, Winter	< 0.01 over 80-percent of area	4° C, 35 % of area 2 – 4° C, 30% of area	> 3	> 4 over 40% of area	
Centrarchids, Summer			> 5		
Centrarchids, Spawning	< 0.016		> 5		
Centrarchids, Nursery	< 0.016		> 5		
Lake Sturgeon	0.35 – 1.3			3 – 13	silt - sand
Shovelnose Sturgeon	0.65 – 1.5			13 - 25	sand
Paddle Fish	< 0.16			13 – 25, > 19 is preferred	

The physical conditions for Lake Sturgeon, Shovelnose Sturgeon, and Paddle Fish was discussed at a meeting between researchers, managers, and engineers on April 15, 2003. The purpose of the meeting was to explore the possibilities of creating this type of habitat with island projects. It is an example of some of the research that has been occurring on the UMRS and of what pro-active communication can accomplish.

Knights et al., 2002, based on a study of radio tagged Lake Sturgeon, found that core areas and other sites used extensively by lake sturgeon appeared to contain hydraulically similar conditions characterized by transition from high current velocities to slower velocities. These transition areas which are due to local changes in river morphometry, result in depositional substrates (ie. silt-containing) and probably represent important feeding habitats for lake sturgeon Examples of existing areas with these physical conditions include: areas in or near impoundments, the confluence of the main channel with large secondary channels or tributaries, and the boundary between the main channel and main channel border in impounded reaches. The lake sturgeon tagged during this study moved over a large geographic extent (as much as 100 miles) but they frequently returned to and used the core areas.

The data on Shovelnose Sturgeon is from research in Pool 13 (Hurley et al. 1987, Curtis et al. 1997), the LTRMP Open River Field Station, and UMESC trawling data in Pools 10 and 26. The shovelnose sturgeon used small home ranges, described as being 50 meters in length, for extended periods, but could move large distances (as much as 120 miles), usually returning to their home range. Observed shifts in fish location were noted based on the flow regime.

Zigler et al., 2003, based on a study of radio tagged paddlefish, found that areas used extensively by paddlefish had a combination of deep water, low current velocities, and was often influenced by eddy currents, which concentrated phytoplankton, a major food source. These physical conditions appeared to be more important in determining paddlefish use rather than location in a pool (upstream versus downstream) or aquatic area type (secondary channel versus lower impounded area). Although paddlefish frequently concentrated in specific areas in Navigation Pools 5A and 8 during summer through winter, large-scale movements occurred in both upstream and downstream directions, especially during spring.

Other considerations include rock gradations and woody structure used on island projects. 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. Incorporating woody structure into shoreline stabilization designs could provide fish cover if the near shore depths are relatively deep.

Habitat Parameter 2. Fall Waterfowl Habitat. Table 9.B.2 lists the physical conditions that have been established for dabbling ducks and diving ducks. These were established for the Pool 8, Phase II and Phase III island projects. Key factors to be considered when evaluating migration habitat are fall water conditions, plant species composition and distribution, human disturbance, visual barriers, sandbars/mudflats, loafing structures and thermal protection. Generally a 50/50 mix of open water to emergent/floating leaf vegetation is considered ideal for dabbling ducks. Large bodies of water (> 200 acres) with extensive beds of submersed aquatic vegetation and limited emergent vegetation are generally more preferable for diving ducks.

Islands effectively reduce wave action up to 1 mile downwind of the island, creating conditions more conducive to the establishment and maintenance of vegetation beds. The zone downwind of the island that is completely sheltered from wind is equal to ten times the height of the island plus trees.

Table 9.B.2. Physical Conditions for Waterfowl Habitat

Habitat Type	Velocity (fps)	Wind Fetch	Water Depth, d (feet)	Other Desirable Features
Dabbling Duck Migration Habitat	< 0.5	< 0.5 miles	d < 0.33, 15 – 25% of area 0.33 < d < 2, 40 – 50% of area	sand bars, mud flats, loafing structure, visual barriers,
Diving Duck Migration Habitat	< 0.5	< 1 mile	1.5 < d < 5, 40 – 70% of area	visual barriers

The following is based on information in the literature and input from resource personnel on the UMR.

- Optimum water depths for dabbling ducks to feed are between 4-18 inches. In riverine conditions, deeper water that supports rooted floating aquatic plants and submerged aquatic plants may still provide food plants and invertebrates at optimal feeding depths for dabbling ducks.

- High quality habitat provides a diverse assemblage of preferred food plants as opposed to a monotypic stand of one species. The physical conditions in a riverine system create the potential for the presence of a wide variety of vegetation communities. Shallow (<2 feet), low flow areas that are protected from wind provide ideal conditions for the establishment of emergent vegetation. Deeper areas (>2 but <8 feet) that are afforded some protection from wind provide suitable conditions for a variety of rooted floating aquatic and submersed aquatic vegetation. Each of these communities may provide food/cover plants and invertebrates that are important to waterfowl during migration.

- Loafing sites/structures offer the opportunity for dabblers to rest and conserve energy. Areas with extensive loafing areas are generally higher quality than areas without. Loafing areas can be present in the form of sandflats/mudflats, low islands, tree stumps, muskrat houses or floating vegetation. Several sites scattered throughout an area are better than one large area.

- Protection from prevailing winds during severe weather allows dabblers to conserve energy. Numerous studies on large reservoirs and rivers, and observations by UMR refuge personnel, have shown that waterfowl utilize protected shoreline areas during severe weather. Cutbank shorelines, protected coves, backwater wetlands, large stands of persistent emergent vegetation or islands can all provide the needed structure to provide thermal protection. The presence of this type of habitat, a function of the downwind shadow zone of structures such as islands, on at least 5 percent of the area dramatically improves migration habitat value.

- Emergent vegetation can be an important component of diving duck migration habitat, but not if it is too extensive in coverage. Areas that are predominately emergent vegetation (50 percent or greater) are usually considered to provide minimal migration habitat for diving ducks. Emergent vegetation beds may be used by diving ducks later in the migration season when the plants have withered and the areas are more characteristic of open water.

- Invertebrate populations can be a key food source for diving ducks during migration (especially in the Spring). Many species (such as mayflies, midges and snails) are associated with submersed and rooted floating leaf aquatic vegetation beds. Fingernail clams are also important. Fingernail clams seem to thrive best in areas that are fairly deep (3-8 feet), have flat bottoms and have current velocities between 0.1-0.3 fps.

- Susceptibility of an area to human disturbance may lower the value of an area as migration habitat. Disturbance in a migration area limit feeding opportunities and force the birds to expend energy in avoidance activities. In some cases the disturbances from bird watchers, researchers, fisherman and boaters may have as great an impact on specific birds as the more obvious disturbances such as hunting. Islands and or extensive beds of emergent aquatic vegetation can provide visual barriers between potential sources of disturbance and aquatic habitat. Large areas and multiple lines of barriers may often lessen the disturbance factor.

- The presence of extensive, protected aquatic vegetation beds is important in providing valuable migration habitat for waterfowl. While the design criteria provide conditions that are favorable for the establishment of aquatic vegetation in a mix that is desirable for the target species, it must be recognized that a variety of other conditions may affect the establishment or maintenance of aquatic vegetation including water quality, water levels during the growing season and the presence of invasive species.

Habitat Parameter 3. Aquatic Vegetation. The following information is from Jeff Janvrin, Biologists, WDNR & FWWG member with input from Yao Yin, Heidi Langher, Kevin Kenow, Jim Nissen, Eric Nelson, Sharonne Baylor

Earlier sections of this report have described how island erosion by waves, ice and river currents have reduced the number and acreage of islands in the lower sections of many pools in the St. Paul District. When an island is lost due to erosion, the impact is more than losing some land within the River's floodplain. A chain of events begins to occur. River currents now enter into the once protected area, increasing velocities and uprooting some of the vegetation beds. More vegetation beds are uprooted and lost because of the unchecked energy of waves rolling across miles of open water. The waves continue to build in size and eventually begin stirring up sediment from the bottom. Once the sediment is suspended in the water turbidity is increased, acting like a liquid veil, shading out light the underwater plants need to grow. Islands provide floodplain structure that can reduce the impact of wave action and current on aquatic vegetation.

Meeting the habitat objectives for many island projects includes providing suitable physical and chemical conditions for the germination, growth and maintenance of emergent, floating leafed and submersed vegetation. Aquatic vegetation provides food resources and cover for a variety of species. Aquatic vegetation also provides a wave damping affect that reduces shoreline erosion and sediment resuspension.

The following criteria were developed during planning for more recent HREPs and also include additional criteria proposed by a subgroup of the FWWG for consideration in the design of future island complexes to improve environmental conditions aimed at aquatic vegetation communities. Several of the criteria are based on queries of the LTRMP databases and will require additional analysis to refine the recommendations. This additional analysis is recommended to occur in the near future.

Some of the criteria are presented as a range. Diversity for these will most likely result in colonization and maintenance of a variety of species within the specified community. However, more specific criteria can be developed for specific species by further literature review, queries of the LTRMP database or research. Establishing the objectives will require the planning team to consider the best ecological potential in the area. Ideally, a project should be designed to meet the needs of all aquatic vegetation communities to provide the most habitat benefits. Water depths within the project area will be a major factor in determining the distribution and areial extent of aquatic vegetation communities.

The Pool 8 vegetation SRS data from the Environmental Management Program's Long Term Resource Monitoring Program was merged with a velocity model developed by the COE (90,000 cfs) and the bathymetry data. Table 9.B.3 summarizes the velocity and depth ranges in aquatic areas where emergent and floating leaved vegetation was present at SRS sites from 1998 to 2004. Over 80 percent of the emergent vegetation was present at locations with <0.6 m of water and velocities <0.1 m/sec. Over 80 percent of the floating leaf vegetation was present at locations with <0.8 m of water and velocities <0.1 m/sec. The preferred limit for water velocities is most likely less than indicated by this simple analysis since a flow of 90,000 cfs represents approximately a 2 year flood event.

Table 9.B.3. EMP LTRMP Vegetation SRS Points Where Emergent and Floating Leaf Vegetation Were Present Merged With Water Depths and Velocities (from Model of 90,000 CFS Flow). [1]

	Floating Leaf Vegetation		**Emergent Vegetation**	
Water Depth (m)	**SRS Points Present**	**%**	**SRS Points Present**	**%**
< 0.2	374	45%	350	58%
0.2 - 0.4	135	16%	104	17%
0.4 - 0.6	115	14%	69	11%
0.6 - 0.8	94	11%	35	6%
0.8 - 1.0	71	8%	28	5%
1.0 - 1.2	28	3%	8	1%
1.2 - 1.6	16	2%	11	2%
1.6 - 2.0	4	0%	2	0%
2.0 - 2.5	1	0%		
2.5 - 3.0	1	0%		
Totals	**839**	**100%**	**607**	**100%**
Velocity (m/sec)				
0	666	77%	491	76%
0.0-0.1	75	9%	42	6%
0.1-0.2	77	9%	42	6%
0.2-0.3	24	3%	14	2%
0.3-0.4	11	1%	19	3%
0.4-0.5	8	1%	19	3%
0.5-0.6	3	0%	11	2%
0.6-0.7	2	0%	5	1%
0.7-0.8	3	0%	3	0%
0.8-0.9			1	0%
1.0-1.1			1	0%
Totals	**869**	**100%**	**648**	**100%**

[1] Total points do not equal since model and bathymetry was not available for all areas SRS data was collected

Using the information provided by Table 9.B.3, along with experience and objectives from other projects and design considerations from other sections of this handbook, the following design criteria to promote the establishment and maintenance of aquatic vegetation were developed.

Emergent Vegetation

Water Depth: <0.6 meters
Water Velocities: 0.0 m/sec preferred, <0.1 m/sec acceptable over portions of the area
Substrate: Wide range, but not highly organic/flocculent or pure sand
Wind Fetch/Island Placement: Determine based on equation provided under Engineering Consideration 4: Wind-driven Wave Action for the water depth <2 feet that makes up the majority of area in shadow zone of island (for example, if 75 percent, of the water depth in the shadow zone of the island is 1 foot, then spacing should be based on minimizing sediment resuspension in 1 foot of water).

Rooted Floating Leaf Vegetation

Water Depth: <0.8 meters
Water Velocities: 0.0 m/sec preferred, <0.1 m/sec acceptable over portions of the area
Substrate: Wide range, but not highly organic/flocculent or pure sand
Wind Fetch/Island Placement: Determine based on equation provided under Engineering Consideration 4: Wind-driven Wave Action for the water depth 3 feet that makes up the majority of area in shadow zone of island (for example, if the majority (i.e. 75 percent) of the water depth in the shadow zone of the island is 1.5 foot, then spacing should be based on minimizing sediment resuspension in 1.5 foot of water).

Submersed Vegetation - To be provided by Yao Yin.

Water Depth: <x.x meters
Water Velocities: x.x m/sec preferred, <x.x m/sec acceptable over portions of the area
Substrate: Wide range, but not highly organic/flocculent or pure sand
Wind Fetch/Island Placement: Several different "types" of floodplain structures were recommended for consideration in meeting physical parameters for aquatic vegetation. Several of these structures have been incorporated as features of completed projects: islands; sand/mud flats; seed islands; and isolated wetlands in conjunction with island construction. Bob Drieslein, Refuge Manager (retired) with the Upper Mississippi River Wildlife and Fish Refuge has provided observations regarding vegetation response at the Polander Lake HREP, an HREP that also included the construction of isolated wetlands.

"The best response from vegetation, particularly emergents, was in Interior island No. 1. This was not surprising since this was the one that had the fines pumped into it. Water depths within the three interior islands were in the 2 1/2 - 3 foot range, which is too deep for emergents except on the margins. On island 1 we pumped in fines and reduced water depths to about one foot, which created an environment for emergents to grow. Floating-leaved aquatics like lotus and water lilies responded positively throughout the interior complex. It appears that aquatic plant beds outside the island perimeter have increased in size, due to the shadow effect affording protection from wind and wave action. Diving duck (primarily canvasback) use in the Pool 5A closed area which includes the island complex, was greater in fall, 2004 than in any year since the islands were built."

Water level management, both small scale and pool wide, has been used to provide environmental conditions suitable for the establishment of aquatic vegetation, especially emergent vegetation. The effects of periodic water level management are more prolonged in areas protected from river currents and wind fetch.

Other Design Considerations. Monitoring of emergent vegetation beds that grew in response to water level management in Pool 8 during 2002 and 2003 drawdowns showed herbivory by muskrats and waterfowl can have an impact on the emergent vegetation bed. Observations from these monitoring efforts indicate some consideration may need to be made to reduce suitable habitat for muskrats in some areas. Some potential design considerations to reduce the impacts of muskrat feeding on the emergents include:

- Shallow “breakwater” type islands that would provide poor quality shelter for muskrats
- Greater slopes on the island to prevent burrowing activity
- Provide greater variety of slope of the island (sacrificial berm tie in to the main island) based on water depth/fetch.

Monitoring/Research Needs. The interagency team formed to refine the island design criteria for aquatic vegetation identified several potential monitoring and research needs to better define criteria for the establishment and maintenance of aquatic vegetation. Following is a partial list of these needs, however, many other needs have been identified in other planning efforts:

- Query/analysis of existing LTRMP data to further develop and define physical factors affecting aquatic plant distribution with the Mississippi River floodplain.
- Impact of velocity on germination and growth of various types of aquatic vegetation.
- Affects of island on seed and tubor transport and settlement.
- Impacts of animal feeding activity on aquatic vegetation.
- Changes in animal use patterns after island construction.
- Complimentary benefits of island construction and water level management:
    - Affect of island and water level management on distribution of submersed vegetation.
    - Animal use patterns before and after island construction and water level management.

Habitat Parameter 4. Terrestrial Vegetation on Islands. The Anfang and Wege Report (2000) provides a large amount of information on the establishment of vegetation on islands and dredge material placement sites. The following observations by Anfang and Wege are listed because of their direct implications for island projects.

- The establishment of vegetation on HREP projects was successful and helped reduce site erosion, improved aesthetic appearance, and provided valuable wildlife habitat.

- Fine material increased the density of vegetation (both planted and naturally occurring).

- 6 inches of fine material should be the minimum used for capping. The percent cover was highest on vegetation sites that were capped with more than 1 foot of fine material. A thicker cap of fine material with a higher percentage of fines may encourage a dense growth of woody and herbaceous cover.

- A higher percentage of seeded species were dominant on sites with more than 1 foot of fine material (68 percent) than on sites with less fine material (56 percent).

- Fine material sites with more than 35 percent silt/clay had a higher average percent cover than sites with lesser amounts. At least 15 percent fines in the topsoil is sufficient to establish vegetation, however.
- The fine material should contain sufficient coarse material to allow for aeration and water infiltration. This should be included in the specifications for the project.
- Switchgrass was recorded as the most common species on vegetation sites twice as often as any other species. At some sites the high density of switchgrass may have reduced the abundance of other vegetation by shading or other means.
- It may take several growing seasons (three to six) before vegetation reaches a desired/maximum density.
- The monitoring effort could not explain why some vegetation sites quickly convert from grasses to dense herbaceous and woody vegetation. Possible explanations include the proximity of some sites to other woody vegetation, whether or not the site was seeded to grass in the first place, the elevation of the site (higher sites favoring grasses), and the depth and consistency of fine sediments used as topsoil.
- 8 inches of fine sediment is too much for disking with standard farm equipment.

The following reforestation and revegetation recommendations and guidelines were provided by Kurt Brownell and Randy Urich, Foresters, St. Paul District

Soils

- Coarse, sandy dredged material is a poor medium for plant growth. It is important to incorporate some form of organic material with the sand to provide a suitable environment for seed germination, plant establishment and survival. To date, UMR revegetation projects have generally utilized fine sediments dredged from backwaters for topsoil. This has worked well. Sewage sludge and compost are other options being explored on a limited basis.
- Fine material placement techniques that have worked successfully include: mechanical dredging in backwaters with placement using front-end loaders; hydraulic dredging in backwaters using containment cells for placement on the site and follow-up spreading and incorporation with heavy equipment; use of an irrigation sprayer to apply fine material dredged from a backwater using a small hydraulic dredge; and use of dump trucks to deliver topsoil where the project site is accessible by land.
- Ideally, fine material and soil amendments should be incorporated into the base material. As a general rule, 6-12 inches of soil depth will support bottomland hardwood trees. Six inches of soil depth is often suitable for planting grass and forbs, with dry prairie species possibly requiring a bit less.
- Fine sediments with a high percentage of clay may be more difficult to establish trees on. This is especially true if there is significant compaction from heavy equipment during construction. One potential solution is the use of power augers during tree planting to loosen the soil in the planting hole.

- To help promote long-term survival and health of vegetation plantings, project sponsors should be encouraged to monitor soil nutrient levels at reasonable intervals after the project is completed. Color and condition of foliage plus plant size may be used as an initial indicator. If a problem is suspected, a soil test will confirm the nutrient levels and can be arranged through local extension offices. Follow-up action may include application of fertilizer.

- Soil erosion can be very effectively controlled using vegetation. However, soil-holding capabilities vary between plant type and species. It is important to consult a vegetation specialist during the island planning and design phase to help with plant selection.

Elevation

- Even within the floodplain, the flood tolerance of different plant species varies considerably. Elevation differences of six inches or less can determine whether a site will support certain types of plants. Therefore, it is very important to match plant species to island elevations. A good general reference is Whitlow, T. H., and Harris, R. W. (1979), *Flood tolerance in Plants: A State-of-the-Art Review, Technical Report E-79-2*, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS., NTIS No. AD A075 938.

- Post-construction flooding on low elevation islands usually results in establishment of new plant species from seed that is washed onto the site. Sometimes this new vegetation can significantly change the original composition and density of plants, and often includes undesirable species, such as vetch, purple loosestrife, reed canary grass and others. Therefore, it is recommended that simple, relatively inexpensive planting mix be used on these lower areas.

- Mast is an important diet component of many wildlife species and the most important mast-producing tree found within the bottomlands of the upper Mississippi River in the St. Paul District is swamp white oak (*Quercus bicolor*). The La Crescent Natural Resource Project Office surveyed a number of locations in 2003 and determined that the average minimum elevation above mean pool elevation where swamp white oak occurs is 2.17 feet, and for black oak (*Quercus velutina*) it is 3.01 feet. While this conclusion is based on data from only three pools, it at least establishes rough guidelines.

- Consider flood frequency and current velocity before using tree shelters on low elevation islands. Floodwaters can tip over or remove shelters, resulting in dead, deformed or damaged trees. Tree mats may not hold up on low areas either, but are more likely to stay in place than shelters. The weed control that mats provide may still be worth the risk of using them on low areas.

- An excellent set of modeling tools are available to assist in selecting sites, trees species, and tree sizes for successful reforestation. These flood potential models for the Upper Mississippi and lower Illinois Rivers are available from USGS at http://www.umesc.usgs.gov/reports_publications/psrs/psr_2001__01.html. The reference is Wlosinski, Joseph H. and Laurie B. *Predicting Flood Potential to Assist Reforestation for the Upper Mississippi River System.* Islands have the potential to support diverse stands of vegetation that can then provide benefits such as wildlife habitat, visual barriers, and protection from wind. Vegetation types include bottomland forest, grassland, and shrubby woody vegetation. Designing islands with diverse topographic relief provides managers with a greater number of vegetative options

Grass and Forbs

- Recommend using a diverse mix of native grass and forbs to ensure good overall survival. Wildflowers can enhance the appearance of the site.

- An excellent reference is Wege, G. and Anfang, R. (2000). *Summary of Vegetation Changes on Dredged Material and Environmental Management Program Sites in the St. Paul District, Corps of Engineers*, Corps of Engineers and Fish and Wildlife Service report.

- The Spring Lake EMP project delivery team designed two grassland seed mixes in 2004 for use on islands as shown in the following two tables. For sections of islands where vegetative management will be minimal, the abbreviated prairie mix should provide a relatively quick cover of native species. On higher sections (4 feet above average pool), the diverse prairie mix is recommended. Planners should be advised that active management is required to maintain a grassland on the river, to include mowing during establishment of the stand and periodic controlled burns later to control invasive species and woody vegetation. In addition to providing habitat benefits, native prairie grasses form deep, dense root systems that will ultimately provide more protection to the islands.

  On projects where mulch is utilized, planners should consider weed-free certified mulch. The Minnesota Department of Transportation has such a program and vendors are listed on their website. By using this mulch, the risk of infesting your island with an invasive plant species is much reduced.

Abbreviated Prairie Mix

Common name	Scientific name	Seeding rate (ounces per acre)
Virginia wild rye	*Elymus virginicus*	48
Wild canada rye	*Elymus Canadensis*	48
Switchgrass	*Panicum virgatum*	32
Indiangrass	*Sorghastrum nutans*	16
Prairie cordgrass	*Spartina pectinata*	3
Black-eyed susan	*Rudbeckia hirta*	2

Diverse Prairie Mix

Common name	**Scientific name**	**Seeding rate (ounces per acre) PLS**
Big bluestem	*Andropogon gerardii*	25.5
Little bluestem	*Andropogon scoparius*	25.5
Sideoats grama	*Bouteloua curtipendula*	25.5
Rough dropseed	*Sporobolus compositus*	1
Virginia wild rye	*Elymus virginicus*	25.5
Wild canada rye	*Elymus canadensis*	25.5
Switchgrass	*Panicum virgatum*	4
Indiangrass	*Sorghastrum nutans*	25.5
Prairie cordgrass	*Spartina pectinata*	2
Black-eyed susan	*Rudbeckia hirta*	3
Evening primrose	*Oenthera biennis*	2
Purple prairie clover	*Dalea purpurea*	3
Brown-eyed susan	*Rudbeckia triloba*	2
Yellow coneflower	*Ratibida pinnata*	2
Bergamot	*Monarda fistulosa*	1
Blue vervain	*Verbena hastate*	1.5
Hoary vervain	*Verbena stricta*	1.5
Sky blue aster	*Aster oolentangiensis*	0.5
Frost aster	*Aster pilosus*	0.5
Showy sunflower	*Helianthus laetiflorus*	0.5

Trees

- It is important to quickly establish vegetation in the littoral zone of newly created islands in order to protect them from erosion. Black (*Salix nigra*) and sandbar willow (*Salix exigua*) cuttings have been successfully planted on EMP islands in the past and are planned for future projects. Cuttings are collected in the spring prior to leaf-out and are cut 20-25 inches long, as straight as possible, and range from 3/8 to ¾ of an inch in diameter at the small end. They should be planted as soon after cutting as possible, or stored properly. If planting will take place within a few days, the cuttings may be kept safely by placing the butt ends in water, or by heeling-in in moist soil. Cover with wet burlap sacks to prevent exposure to sun or wind. If longer storage is needed (i.e. until after the start of the normal growing season), the cuttings should be placed in cold storage with temperature between 28 and 32 degrees F.

  The cuttings may be bundled together, stacked, and covered with moist burlap. Moisture should be maintained by lightly sprinkling with water as needed. Planting rods made of rod iron with a handle and step, or small power augers have been used successfully to plant cuttings quickly. If soil moisture is high, the cuttings may be pushed into the ground by hand. If rods or augers are used, the cuttings should be pushed to the bottom of the hole to prevent air voids. Approximately 5 inches of cutting should remain above ground and the top of the hole should be closed with a kick of the heel. Eastern cottonwood (*Populus deltoides*) cuttings can also be planted above the littoral zone on newly created islands using similar techniques. Other species that can be established easily with cuttings are dogwoods (*Cornus sp.*) and indigo bush (*Amorpha fruticosa*).

- Willow and cottonwood seedlings often regenerate naturally and fairly quickly on sites at low elevation. In some cases, it may be possible to rely on natural regeneration, in combination with a protective cover of grass, to meet vegetation establishment goals. These sites may eventually succeed into floodplain forest. However, the potential exists for invasive species such as reed canary grass (*Phalaris arundinacea*) to form dense monocultures. Actively planting islands is the preferred option in most cases.

- Consideration should be given to using large-sized (3 feet or greater) tree seedlings for reforestation of bottomland hardwoods. Although the cost for planting materials and labor for planting are higher, survival and growth are generally better. In addition, the larger seedling stock can be planted at a wider spacing, saving on overall costs. Most private nurseries and some state nurseries can supply large seedlings. A fairly recent innovation in tree seedling production is the RPM tree, or root production method. Local tree seed can be collected in the vicinity of the project site 18 months prior to construction, then delivered to the nursery where the seed is grown into RPM seedlings. Average seedling height when ready for transplant is 4-7 feet. Survival and growth characteristics of these seedlings have been excellent, mainly because of the robust root systems that are produced in the RPM process. RPM seedlings can be available for either fall or spring planting.

Establishment

- Tree plantings have been successfully established in both the spring (mid-April to mid-June in MVP) and fall (mid-Oct to mid-Nov in MVP). Seedling availability from nurseries is usually better in the spring.

Long Term Maintenance

- Tree plantings need weed control for a minimum of three years. Tree mats can provide this and are highly recommended at the time of planting. But depending on the height growth of surrounding grasses, even trees with mats may need weed control for several growing seasons after they are established.

- Tree shelters also require regular maintenance. Floods and wind can tip the shelters over or cause them to lean. Other vegetation can grow up inside the tube and choke out the seedling. Use caution when cleaning out tree shelters during the summer and fall as they sometimes contain bee and wasp nests inside the tube.

Other Considerations

- Tree shelters come in various heights. Four to five foot tubes are good if the potential for deer damage is severe. However, shorter tubes (2-3 foot) may be adequate for protection from other animal damage. Of course, the shorter tubes are cheaper and easier to install.

- At low elevations, tree shelters can collect significant amounts of sediment during flood events, sometimes causing seedling mortality.

- Avoid using tree shelters on plantings where prescribed fire is to be used within five years of project completion.

- If possible, avoid row planting of tree seedlings to make the site look more natural and improve aesthetics.

- Quality assurance is very important during contract planting operations to ensure seedling survival and success. Among the critical items to check for is how well the planting stock was protected during storage and handled during planting. The sensitive roots of seedlings must be kept cool, moist, and out of the wind and sun from the moment they are lifted out of the nursery bed until they are covered with soil in the transplant location.

- Quality assurance is also very important in verifying the source of planting materials. The general guideline is to acquire materials where the seed source is within 200 miles of the project location. Closer is better. The seed source should also be from a parent plant that actually germinated and is growing in a floodplain environment.

- Voles and other rodents can cause severe damage and mortality to tree plantings by girdling the lower stems and/or roots. Tree shelters, tree wrap, and rodent repellants are among the options that have been used to address this problem. However, tree shelters must be properly installed so as not to leave a gap at the base of the tree for rodents to enter.

Habitat Parameter 5. Loafing Habitat. Islands and associated shoreline stabilization structures provide loafing habitat for many species (Photo H.14). 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.

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. Two to 12 inches or more above summer levels are 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 and 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. The best species are black locust, white oak; the worst species are 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.

    - We have not completely addressed the effects of ice on the log structures. 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 will not 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.

Habitat Parameter 6. Nesting Habitat. The following is a brief synopsis of parameters that have been established for nesting habitat.

Waterfowl. The following information is from Randy Devendorf, Biologist, USACE.

Establishment of adequate vegetation cover on islands can provide nesting habitat for waterfowl. While isolated wooded islands can provide suitable nesting habitat, dense grassy vegetation is preferable. Large islands may be designed to provide waterfowl nesting habitat, but they may become a significant management issue if predators become established on the island. The following criteria have been identified by UMR resource managers as guidelines for islands designed as nesting habitat:

- Locate island at least 1/2 mile from the nearest land
- Locate island within 1/2 mile of brood habitat (emergent aquatic vegetation)
- Size: <1 acre (< 1/2 acres is ideal)
- Vegetation cover should have an obscurity reading of at least 1.5 dm (6 inches)

Islands. The following information is from Mark Anderson, Biologists, WDNR & FWWG member:

- 0.1 to 5 acres. in size, 0.5 to 2.5 acres preferred
- At or above 10 yr. flood elevation (5 yr. minimum)
- 700 feet or more from permanent shoreline
- Adjacent to brood cover, "hemi" marsh or emergents interspersed with submergents
- Free of mammalian predators - small (.5 to 1 acre) islands are best in this regard
- No trees or other perches higher than 4 feet

Grassy and herbaceous cover, dominated by grasses is the preferred vegetation. Scattered brush, grapevines and small trees are acceptable. Woody plants need to be controlled by periodic prescribed fire, which will also rejuvenate the vigor of the nesting cover. Approximately every 5 years is a common interval. Residual (from previous growing season) cover should provide at least 70 percent visual blocking at a .3 foot height. 100 percent visual blocking (of a Robel Pole) is greatly preferred. Fertilization is not needed for establishment if 1 foot or more of fine particle soils are used to cap the island. Prairie grasses, like switchgrass, are preferred since they resist flattening by snow better than most cool season grasses. Please refer to seed mix #2 being used at Spring Lake (Pool 5) and the Pool 8, Phase III islands.

Turtles. The following information was obtained from Scot Johnson, MDNR and FWWG member.

Island Location

Aquatic Plants. Islands should be designed and located as to support the development of aquatic plant beds and protect existing plant beds. Aquatic plant beds in shallow backwater areas provide cover and food resources for nesting turtles and are necessary to insure the recruitment of hatchlings into the turtle communities. Following nest emergence, hatchlings tend to move towards protected areas with aquatic vegetation. Aquatic plants also provide staging areas for nesting turtles (some species are capable of producing two or more clutches of eggs over a single nesting season). Aquatic vegetation can provide a refuge from higher flow velocities during moderately high discharge periods.

Islands should be designed to break up long, open-water wind fetches in order to reduce wind wave heights, resuspended sediments, island erosion, and protect aquatic plant beds.

Pond/Backwater Turtles Species. Nesting sites should be located near shallow waters (<6 feet depth) that are well vegetated in a mixture of submersed and emergent plants. Soft to moderately soft substrates in shallow water with little to no flow velocity is desirable for over-wintering turtles. Coarse woody debris and rock groupings can be used to create flow velocity shelters near the bottom of the backwater within these over-wintering areas.

River Turtle Species. Nesting sites should be located near low to moderate flow velocity areas during the open water season with water depths ranging from shallow to very deep (20 feet +). Well to moderately vegetated areas should be in close proximity to the deeper water. Over-wintering refuges are found in areas with low velocities, water depths ranging from 8 to 30 feet. Again, large woody debris and rock can be used to create zones of reduced flow velocities near the bottom to improve over-wintering conditions.

Island Spacing. Islands spaced 500 feet apart or greater may reduce predation rates. Sparsely vegetated islands located some distance away from large, moderately vegetated islands may provide a refuge from high predation rates. It is recognized that islands spaced too far apart may reduce their effectiveness in reducing wind generated waves and their associated problems.

Deadwood/Loafing Structures. Map turtle densities have been correlated to nearby deadwood densities. The incorporation of deadwood into island design would provide refuge, basking, over-wintering and foraging areas for all size classes of riverine turtles. Deadwood placement should not be uniform but rather include the clustering of varying size branches and trunks entering the water at irregular intervals, various angles and elevations. Large woody debris, coarse woody debris and deadwood are terms used to describe tree snags and can be used interchangeably. Additional guidance on loafing structures (tree snags placed near shore and for the most part above water) has already been provided by the FWWG.

Rock Shoreline Protection. Rock shoreline protection and offshore mounds should be avoided in areas designed to attract nesting turtles to avoid accidental trapping of hatchlings. Rock can be a trapping hazard for some adult species of turtles as well. Rock groins and vanes may be better

UPPER MISSISSIPPI RIVER SYSTEM
ENVIRONMENTAL MANAGEMENT PROGRAM
DESIGN HANDBOOK

CHAPTER 9

ISLANDS

APPENDIX C
ENGINEERING CONSIDERATIONS

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CHAPTER 9

ISLANDS

APPENDIX C
ENGINEERING CONSIDERATIONS

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APPENDIX C
ENGINEERING CONSIDERATIONS

Engineering considerations are a broad category of knowledge relating to the physical response, impacts, or properties of islands and associated structures. After goals and objectives for a project have been set, they are considered for identifying actions and measures, establishing design criteria, and developing plans and specifications. Most of the engineering considerations listed here are based on knowledge of river mechanics and sediment transport. They may have been extracted from engineering manuals and adapted to island design or they could represent a summary of engineering analysis that has been done for island projects.

Engineering Consideration 1: Shoreline Stabilization. Shoreline stabilization for islands should be designed using the following steps:

1. Determine if stabilization is needed by doing an erosion assessment using the score sheet shown in table 9.C.1. First-hand knowledge of erosion problems should supersede this assessment.

Table 9.C.1. Erosion and Stabilization Assessment Worksheet

Erosion & Stabilization Assessment Worksheet

			Location:									
			Shoreline 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 Score	0	0	0	0	0	0	0	0	0	0

Total Score >18, Bank Stabilization Needed
Total Score = 12 to 18, Further analysis needed
Total Score < 12, Bank Stabilization Not Needed

Reach Descriptions
Reach 1 -
Reach 2 -
Reach 3 -

2. Decide which of two approaches will be used to deal with erosion. The first approach is to harden the shoreline with additional rock, or in some cases increased vegetation, to make it more resistant to erosion. The second approach is to eliminate or reduce the magnitude of the erosive force so that the shoreline in its existing condition will not erode. This can be done by establishing woody vegetation on the berms, by building offshore structures of rock or wood, or by spacing islands so that wind fetch is kept to an acceptable level.

3. Use the information in table 9.C.2 to determine what type of stabilization to use.

Table 9.C.2. Shoreline Stabilization Designs Recommended for Islands

Erosion Process	Nearshore Bathymetry	Marine Plant Access	Stabilization Design
River Current	deep (> 3')	yes	Revetment Vanes
		no	Revetment Vanes
	shallow (< 3')	yes	Revetment Vanes Off-Shore Mounds Vegetation
		no	Revetment Vanes Off-shore mounds Vegetation
Waves	deep (> 3')	yes	Revetment
		no	Revetment
	shallow (< 3')	yes	Groins Rock Wedge Vegetation
		no	Groins Offshore Mound Rock Wedge Vegetation

4. Use figure 9.C.1 to determine berm width. Adequate material must be provided in the berm so that some of the berm material can be eroded during beach formation, and leave at least 15 feet of berm width so that a swath of woody vegetation will protect the main part of the island. Woody vegetation provides rigid stems which protects the main part of the island during floods.

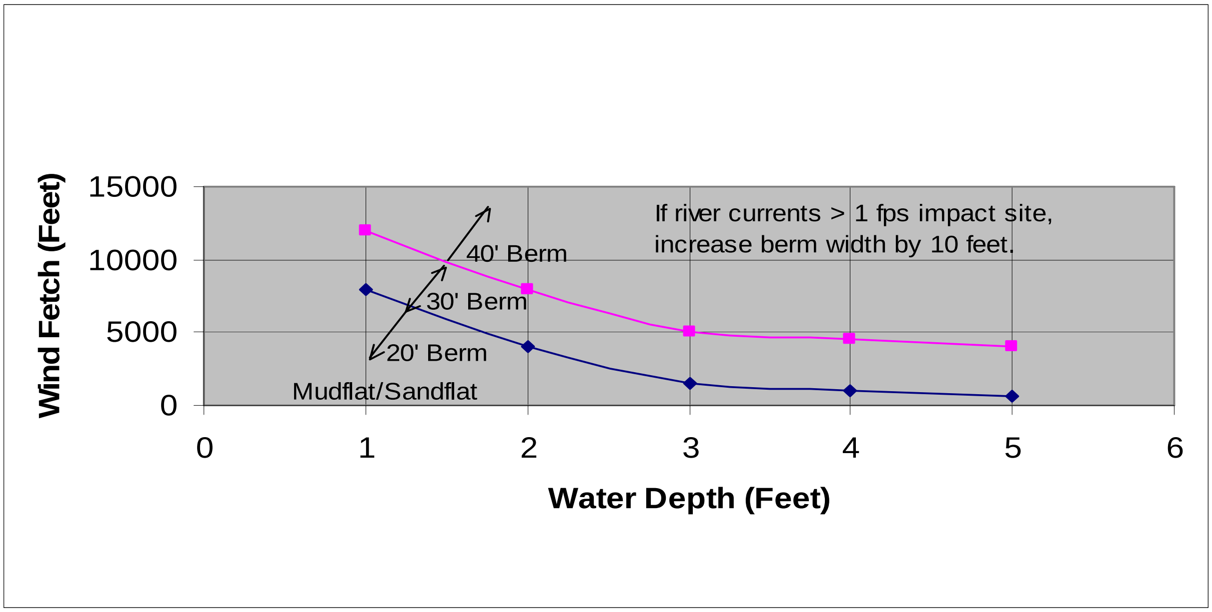

Figure 9.C.1. Berm Width Versus Wind Fetch and Water Depth

5. On shorelines that are extremely sheltered, use vegetative stabilization.

6. On shorelines exposed to significant wave action, rock groins are constructed perpendicular to the berm to prevent longshore transport of sand. Groins are usually 20 to 40 feet long, have a 3 foot top width, 1V:1.5H side slopes and are spaced at a distance equal to 6 times the groin length. Offshore rock mounds can be used instead of groins to add diversity to an island shoreline or if shallow depths inhibit access to the shoreline by construction equipment. Rock mounds only need a top elevation at or just above the average water surface to act as wave breaks, however they are usually constructed to an elevation 2 to 3 feet over the average water surface to account for settlement and sluffing due to wave and ice action. Rock mounds are very expensive to construct.

7. On shorelines where river currents are the primary erosive force, the same berm design as described above can be used except that vanes are used instead of groins. Vanes redirect river currents and move erosive secondary flow cells away from the shoreline. Vanes are 30 to 50 feet long, have a 3 foot top width, 1V:1.5 H side slopes and are spaced at a distance equal to 4 times the vane length. Vanes are angled upstream 30 to 45 degrees with the shoreline and decrease in elevation from 2 feet above the average water surface at the shoreline to 1 foot below the average at the riverward end.

8. The potential for ice action seems to be proportional to the size of the water body. Large backwaters like Lake Onalaska, produce the most problems. Ice action can occur due to freeze thaw expansion of the ice pack or due to wind stresses during breakup. If severe ice action occurs in the project area, berm width should be increased, rock size increased, and rock slopes flattened. Groins should not be used, as they are too easily damaged by ice (photograph 9.C.1) .

Photograph 9.C.1. Lake Onalaska, Pool 7. These groins were constructed so that they extended into the water 30 feet. Ice action pushed the rock on to the beach.

Studies done at the Corps of Engineers' Cold Regions Laboratory recommended maximum rock sizes 2.5 times the average ice thickness and rock slopes of 1V:3H or flatter, if ice conditions are severe (Sodhi, 1997). Problems occurred at the Lake Onalaska island project when ice action displaced riprap which had been constructed at a 1V:3H slope. These problems were compounded by the fact that the berms on these islands were only 20 feet wide. Based on this experience, if ice action is expected to be a problem, rock features should be constructed with 1V:4H slopes or flatter and berm widths should be increased to 40 feet or more.

Engineering Consideration 2: Reducing Sediment Loads But Increasing Sediment Trap Efficiency. Islands reduce the flow of water and sediment to backwater areas or selected parts of backwater areas. This decreases flow velocities, which is usually a necessary step in improving habitat. However, the trap efficiency of the backwater area sheltered by the island is increased so sediment that does enter is more likely to deposit there. This is compounded by the fact that wind-driven wave action and sediment resuspension, which results in export of sediment from backwaters, is also reduced. In-other-words, an island project may have reduced the sediment input to an area, but the sediment removal mechanisms, river currents and wave action, have also been reduced. Objectives for more recent projects recognize this fact and include features such as rock sills, and strategically placed islands to manage deposition and erosion so that habitat is diversified and sustained. The only way to maintain floodplain depth is to completely eliminate the supply of sediment (which is rarely an option) or to construct islands at a low enough elevation so they are overtopped by annual floods, which potentially could scour sediments from the backwater. This takes advantage of the fact that the sediment-discharge relationship in pools 1-10 is relatively flat at higher discharges (figure 9.C.2). This occurs because the sediment transport load is supply-limited, resulting in low sediment concentrations during floods. Sediment concentrations peak near the bankfull discharge and remain steady or sometimes decrease from this point on. By choosing low top elevations, the clean water that occurs at higher discharge is conveyed over the island and through the project area, potentially scouring accumulated sediments carrying them out of the backwater or redistributing them. Recent island projects (Pool 8 Phase II and Polander Lake) have been constructed to lower elevations. The Pool 8 Phase II project included rock sills constructed to about the 2-year flood event and interior islands which force water to move through deeper channels.

Engineering Consideration 3: Island Elevations And Bankfull Flood Elevations in Lower Pools. River restoration efforts usually attempt to establish riverine flow conditions where flow is conveyed in channels for low and moderate flows and significant floodplain flow occurs only after the bankfull flood level is exceeded. Islands, in their most basic form, are the natural levees that separate channels from floodplains. It follows that island height should correspond to bankfull flood levels if the goal is to mimic natural conditions. However, in the lower ends of many of the pools, the elevation that corresponds to a bankfull discharge is often less than the low flow elevation due to the way the locks and dam are operated. Constructing an island this low eliminates any chance of maintaining grass cover on the island since woody vegetation quickly takes over. Also, the operation of construction equipment could be more difficult on a surface this close to the water elevation. For this reason, island elevations are usually higher than bankfull. Low elevation rock sills can be incorporated into the design to increase the amount of floodplain flow. However even these structures usually end up being higher than the bankfull flood event because of habitat considerations in the project area. For instance, creating the low flow conditions for over-wintering fish habitat usually results in the rock sills being set at a higher elevation than bankfull to minimize the chance overtopping during late fall high water events.

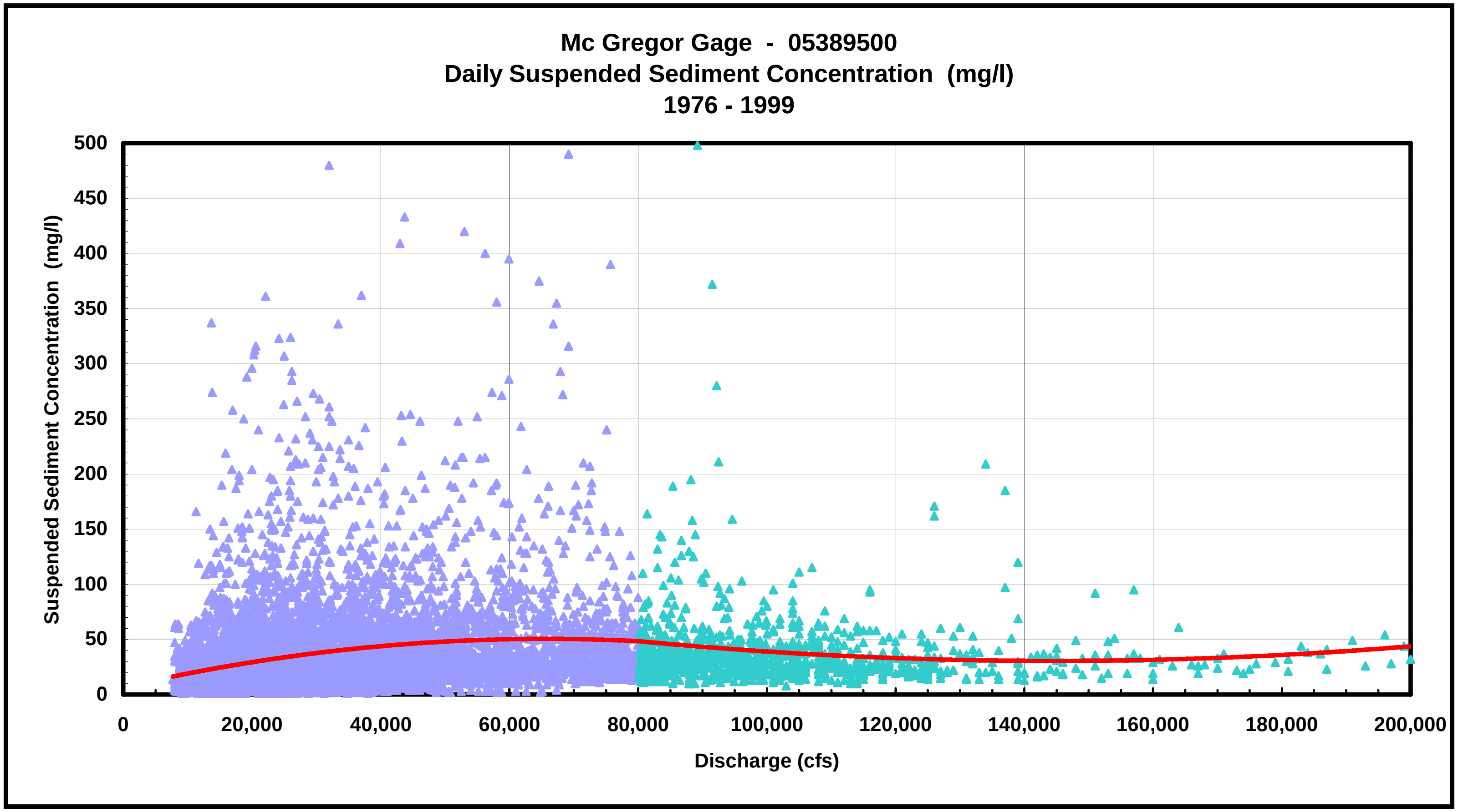

Figure 9.C.2. Suspended Sediment Data at McGregor, Iowa Showing the Relatively Low Concentrations That Occur at Higher Discharges

Engineering Consideration 4. Wind-driven Wave Action. Islands effectively reduce wind driven wave action and the resuspension of sediment by waves up to 1 mile downwind of the island. As wind is deflected up and over an island and its trees, a sheltered zone is created on the downwind side of the island. This zone is roughly 10 times the height of the island and its trees (Ford and Stefan, 1980). The value of this sheltered zone hasn't been stated in a quantitative fashion, however providing thermal refuge for migrating waterfowl is a desirable outcome of island projects. This sheltered zone should contain aquatic plants, invertebrates, and other forms of food for it to be of value, which is another reason to position islands so they shelter shallow water.

Beyond the sheltered zone, waves start building as wind exerts shear stress on the water surface. Each wave creates an orbital motion in the water column resulting in a bottom velocity and shear stress. If this shear stress exceeds the critical shear stress for particle erosion, sediment is resuspended. Data collected in Weaver Bottoms (Nelson, 1998) indicated a strong relationship between wind and suspended sediment concentrations for low flow conditions but a much weaker relationship as flows approached the bankfull flow event. This transition from Lacustrine to Riverine conditions was due to the increased flow through Weaver Bottoms and higher water levels, which decreased the impacts of wave action on the bottom. A rule of thumb used is that the bottom velocity and shear stress generated by wave action should be less than one half the velocity and shear stress created by flood flows. A wind fetch of 4000 to 5000 feet or less is usually recommended to achieve this. For instance, a wind fetch of 5000 feet, wind speed of 20 mph, and water depth of 3 feet, results in bottom velocities due to wave action of around 0.45 fps (compared to measured velocities during floods that usually approach 1 fps). Other factors such as bathymetry and the location of historic islands usually affect position and spacing as much as the fetch guidance. This is illustrated in figure 9.C.3.

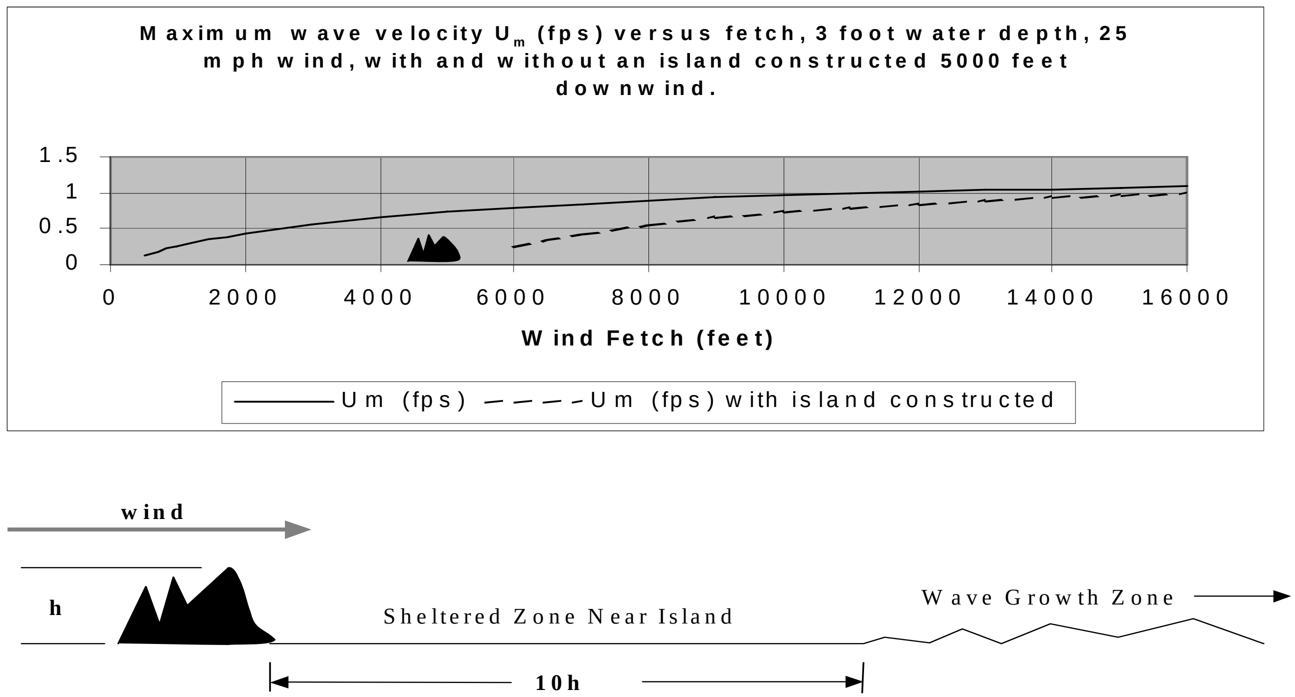

Figure 9.C.3. Impacts of Wave Velocity Created by Wind Fetch With and Without Island Protection

While the rule of thumb given above is adequate for initial planning, island spacing and layout should take into account local bathymetry. As the water depth gets shallower, waves have a greater impact on the bottom. To account for this, the bottom shear stress generated by waves should be determined and compared to a critical shear stress for sediment resuspension. The following equations can be used to calculate wave height, period, and length for deepwater waves, maximum orbital wave velocity, and bottom shear stress. Waves in shallow UMRS impoundments are usually transitional in nature, but the deepwater equations usually do a better job of predicting wave height. Further detail regarding the development of these equations can be found in LTRM Special Report 94-S001 (Chamberlin, 1994).

$$H = .0016\, U_A\, (F/g)^{1/2}$$

$$T = .286\, F^{1/3}\, U_A^{1/3} / g^{2/3}$$

$$L = g\, T^2 / 2\pi$$

$$u_m = \pi H / (T \sinh (2\pi\, d_f / L))$$

$$\tau = \rho\, f\, u_m^2 / 2$$

Where:

H = wave height (meters)
U_A = wind speed (meters/second)
F = wind fetch (meters)
g = acceleration of gravity (9.82 meters/second)
T = wave period (seconds)
L = wave length (meters)
u_m = maximum orbital wave velocity at the bottom (meters/second)
d_f = water depth in the floodplain (meters)
τ = shear stress at the bottom (Newtons/square meter)
ρ = density of water (Kg/m3)
f = friction factor (assumed to be .032)

The value of the critical shear stress for sediment resuspension depends on sediment characteristics such as particle size and cohesiveness, and on aquatic vegetation. Usually there is very little information on sediment properties and the amount of aquatic vegetation varies from year to year. A value of .01 psf seems to match conditions in backwater areas fairly well. For instance, using the deep water wave equations, and assuming a wind speed of 20 mph, the wind fetches that result in a bottom shear stress that exceeds the assumed critical shear stress for sediment resuspension of .01 psf are as follows:

Water depth (feet)	1	2	3	4
Deepwater Fetch (feet)	1500	3500	6000	9000

These wind fetch values could be used as a guide in laying out islands.

The series of images below (provided by Jim Rogala, UMESC, 2005) shows the change in wind fetch in lower pool 8 through time. Wind direction data based on historical frequency of occurrence during the open water period was used to create a weighted fetch coverage. The reduction in wind fetch shown over the last three images are due to island construction in lower Pool 8 through the EMP. The reduction in fetch from 1989 to 1998 is due to the construction of Phase I and Phase II of the Pool 8 Island project. The reduction in fetch from 1998 to 1999 is due to seed island construction. The reduction illustrated from 1999 to 2007 is the expected impact of the Phase III portion of the Pool 8 Island project. A change in fetch is shown in figure 9.C.4.

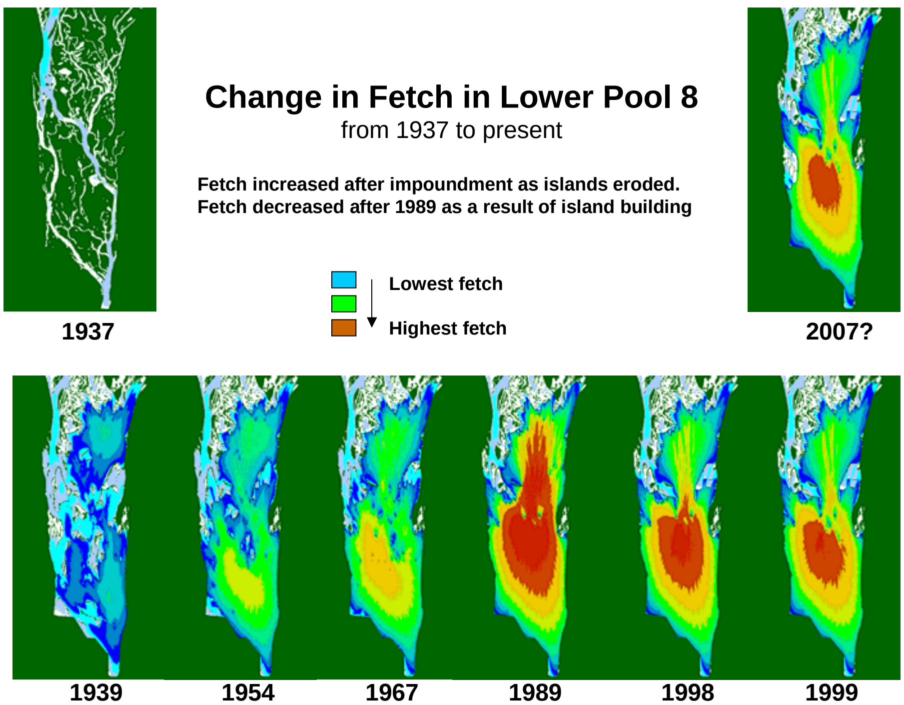

Figure 9.C.4. Change in Fetch in Lower Pool 8

Engineering Consideration 5: Island Width Versus Stability. The hydraulic slope, flow velocity, and potential for erosion decreases with increased island width. The range of widths used on previous projects (70 to 200 foot base width) has resulted in stable islands in all cases. This suggests that island width can be at the lower end of this range, however, the headloss across the island and frequency of overtopping must be considered. Generally, lower sections of island that are overtopped first should be wider than higher sections.

Burrows of animals (mostly muskrats) and subsequent tunnel collapse during Spring highwater conditions results in small trenches that may extend up to 20 feet in from the shoreline. The concern with this is that these trenches could be erosion sites during an overtopping event. This has never been a problem on the wide islands that have been constructed, however it could be a problem if island width was reduced too much.

The present state of island design has focused on meeting aquatic goals and objectives through the construction of the most cost effective and stable island design. However, future island projects that incorporate sand/mudflats, isolated wetlands, and more terrestrial habitat goals and objectives would warrant the construction of islands with larger footprints to meet the terrestrial and other habitat objectives.

Engineering Consideration 6: Beach Formation Process. When sand is placed for the island base, two wind-driven processes begin acting. The first is littoral drift, which is the process of sand moving down a shoreline in response to the angle that waves approach a shoreline from the predominant wind direction. Groins are usually constructed to stop this process, resulting in the scalloped shoreline shape (photograph 9.C.2). This photo shows Grassy Island a couple of months after construction. Wave action and littoral drift have caused the scalloped shape seen here. Sand is eroded from the area between each set of groins and deposits near the groin.

Photograph 9.C.2. Pool 8, Phase I, Stage II, Grassy Island

The second process is beach formation, which results from a combination of offshore transport of sand and from berm erosion due to wave action. Surveys of island shorelines indicate that a beach with a slope of 1V:8H to 1V:12H will eventually be created. The initial berm profile and the final profile are illustrated in figure C.5. Enough material must be placed in the berm so that after the beach formation process has occurred at least 20 feet of berm will remain upon which willows and other woody vegetation can grow. As an example, if the water depth is 3 feet and the beach slope is 1V:10H, a 30 foot wide beach will form. Roughly half of the berm will erode during this process. So with 15 feet of berm erosion, the initial berm width should have been 35 feet for 20 feet of berm to remain.

Wave action results in offshore transport of sand until a stable beach slope is achieved. The as-built berm width, is reduced because of this. The final beach slope varies but a typical value is 1V:10H.

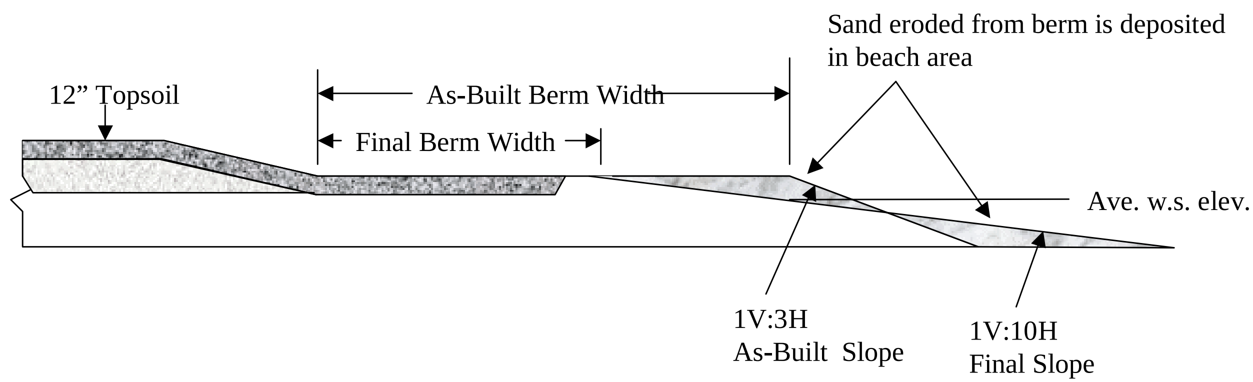

Figure 9.C.5. Reshaping of the Islands Shoreline Due to Wave Action

Engineering Consideration 7: Wood Species for Biotechnical Stabilization. Placing logs along island shorelines or incorporating them into shoreline stabilization structures is desirable from the standpoint of habitat (fish structure, loafing structure and substrate) and aesthetics. Logs with a high specific weight and high decay resistance are desirable since they resist the buoyant forces exerted on them and they will last longer. An excellent reference on large woody debris structures is Shields, et al. (2004). This reference discusses in detail design procedures, costs, and successes of woody debris structures. The information in table 9.C.3 on wood density and decay resistance was developed by the St. Paul District's Natural Resources Office. Black Locust is the most desirable species since it is relatively heavy, decay resistant, and is an undesirable non-native species that is frequently harvested because it tends to dominate forests once it becomes established.

Table 9.C.3. Properties of Wood
Information provided by Randy Urich, Forester, St. Paul District Natural Resources Office

Species	Weight per Standard Cord (pounds)	Weight per Cubic Foot (green)	Decay Resistance
Ash, white	4300	48	Low
Aspen	-	-	Low
Black cherry	4000	45	High
Black locust	5200	58	Exceptionally
Black walnut	5200	58	High
Cottonwood	4400	49	Low
Elm	5000	54	Low
Hackberry	4500	50	Low
Hickory	5700	63	Low
Honeylocust	5500	61	Moderate
Red Cedar	3300	37	High
Silver maple	4300	45	Low
Red oak	5700	64	Low
White oak	5600	63	High

From the standpoint of longevity, it is desirable to place the logs so that they are either above or below the water surface the majority of the time to avoid decay associated with wetting and drying. However, the guidance on habitat loafing structures (habitat parameter 5) should be used to optimize log placement.

Engineering Consideration 8: Seepage Through Rock Structures. Excessive seepage through the voids in rock structures is a concern because of the potentially negative impacts on over-wintering fish habitat. An impervious fabric was included in the rock sills at the Pool 8, Phase II project to reduce seepage, however this nearly doubled the cost of these rock sills. Natural plugging of the voids in rock structures has been documented in the past, however there are other cases where seepage seems to occur for years after the structure is constructed. There doesn't seem to be a consistent set of lessons learned regarding seepage, so it is something that design teams must take into account on a case-by-case basis.

Engineering Consideration 9: Displacement of Sediments. Displacement (or rapid settlement, which occurs during construction) occurs on every project to some extent. The Corps' standard method of measuring displacement is settlement gages, however these don't work for islands built hydraulically because they are always tipped over by the mud wave in front of the sand. At the Trempealeau National Wildlife Refuge (NWR), which involved construction of a dike in open water similar to what is done for islands, displacement of 1.25 feet was measured using post construction borings. The method of hydraulic placement of sand had to be altered to reduce the size of the mud-wave, which inhibited continued placement of sand. The technique ultimately used, involved placing the sand in a wedge-shaped fashion.

UPPER MISSISSIPPI RIVER SYSTEM
ENVIRONMENTAL MANAGEMENT PROGRAM
DESIGN HANDBOOK

CHAPTER 9

ISLANDS

APPENDIX D
PROJECT PHOTOGRAPHS

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St. Paul District

Photo A.1: Weaver Bottoms Constructed 1986 Swan & Mallard Island, Whitewater River

Photo A.2: Weaver Bottoms Hydraulic dredging of fine sediments into a containment cell constructed on Swan Island

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St. Paul District

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of Engineers
St. Paul District

Photo A.3: Weaver Bottoms
Fine sediments (ie. topsoil) being spread over sand on Mallard Island

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St. Paul District

Photo A.4: Weaver Bottoms
Groins on north side of Swan Island

US Army Corps
of Engineers
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Photo A.5: Weaver Bottoms
Offshore rock mound, Swan Island

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of Engineers
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Photo A.6: Weaver Bottoms Mallard Island Shoreline

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of Engineers
St. Paul District

Photo A.7: Weaver Bottoms
Swan Island Groin

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St. Paul District

Photo A.8: Weaver Bottoms
Swan Island biotechnical stabilization

Wooden stakes with wire strung between them were initially used to anchor the fiber rolls, however wave action soon loosened many of the stakes. The USFWS came up with a simple and effective way to hold the fiber rolls down. Sandbags.

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Photo A.9: Weaver Bottoms Prairie Grasses on Swan Island

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St. Paul District

Photo B.1: Lake Onalaska Constructed 1989 Sheltered zone downstream of islands

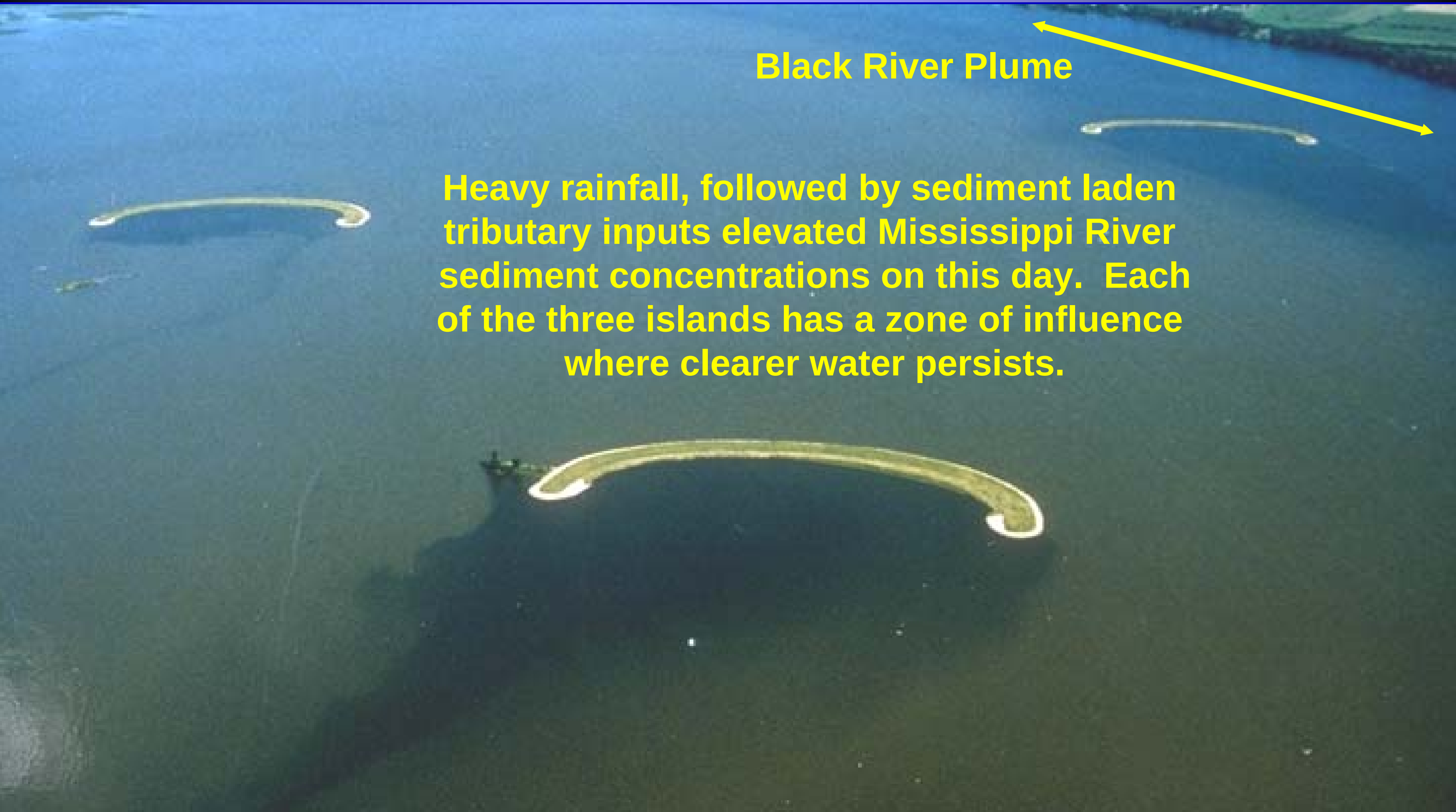

Photo B.2: Lake Onalaska Comorant Island before topsoil

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St. Paul District

Photo B.3: Lake Onalaska
Comorant Island before vegetation

US Army Corps
of Engineers
St. Paul District

Photo B.4: Lake Onalaska Broken Gun Island 1989

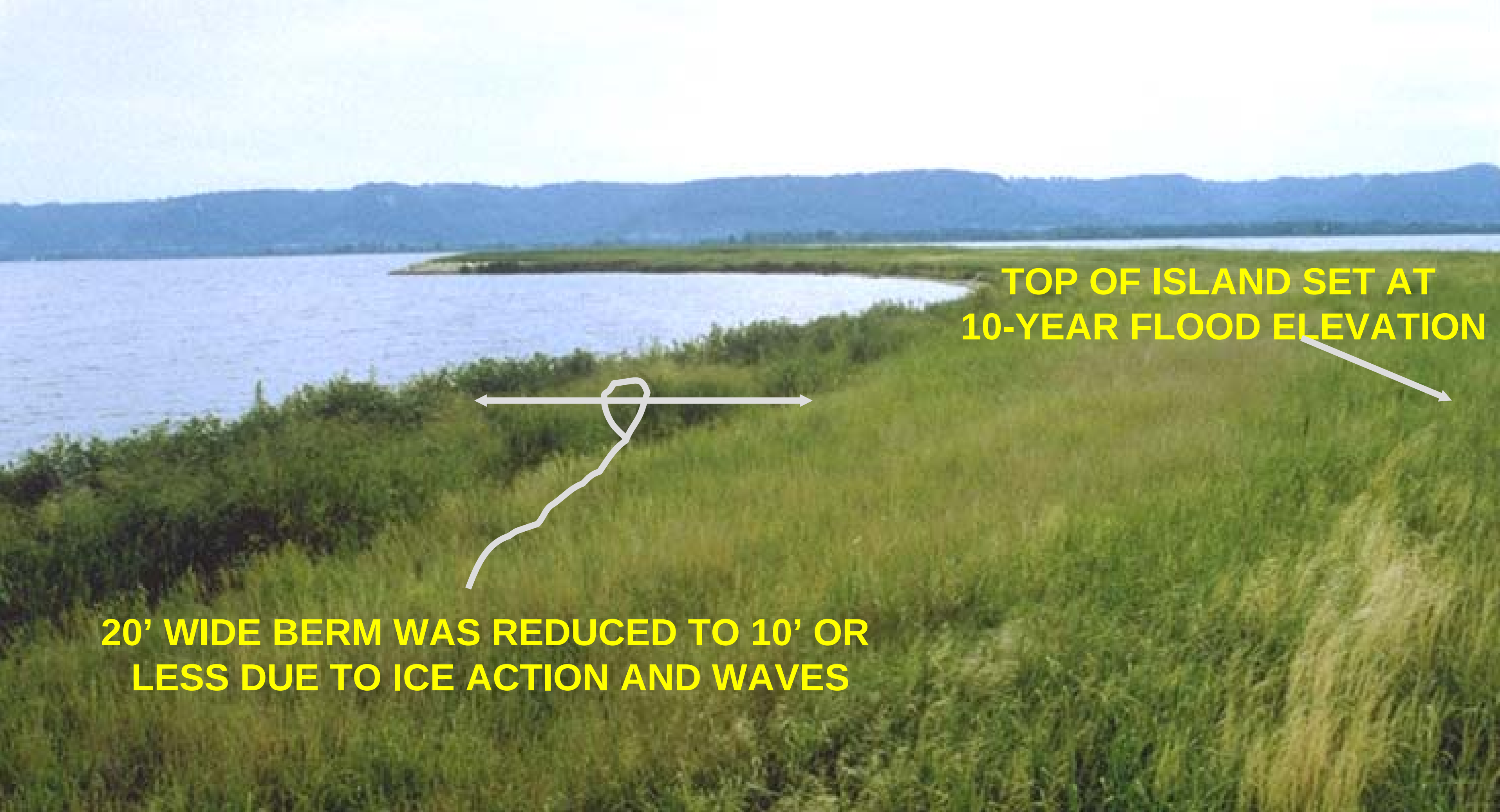

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Photo B.5: Lake Onalaska Riprap and Geotextile

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Photo B.6: Lake Onalaska
Ice action at Broken Gun Island

US Army Corps
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Photo B.7: Lake Onalaska
Ice damaged groins

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of Engineers
St. Paul District

Photo C.1: Pool 8, Phase I, Stage I
Constructed 1989
Horseshoe Island

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of Engineers
St. Paul District

Photo C.2: Pool 8, Phase I, Stage I
Horseshoe Island stable shoreline

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St. Paul District

Photo C.3: Pool 8, Phase I, Stage I Willow growth on sand berm less than one year after construction

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of Engineers
St. Paul District

Photo D.1: Pool 8, Phase I, Stage II
Constructed 1992
Boomerang Island

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Photo D.2: Pool 8, Phase I, Stage II Constructed 1992 Grassy Island

Photo D.3: Pool 8, Phase I, Stage II
Fines placed on Sand Base

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St. Paul District

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Photo D.4: Pool 8, Phase I, Stage II
Boomerang Island Construction

Photo D.5: Pool 8, Phase I, Stage II
Stable during 1993 flood
Note green rows of grass beneath water

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Photo D.6: Pool 8, Phase I, Stage II Vegetative stabilization on Boomerang Island

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Photo D.7: Pool 8, Phase I, Stage II Erosion at Boomerang Corner

Photo D.8: Pool 8, Phase I, Stage II Sparse ground cover after 2001 flood Boomerang Corner

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Photo D.9: Pool 8, Phase I, Stage II Biotechnical stabilization consisting of groins, sand berm, and willows

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Photo D.10: Pool 8, Phase I, Stage II Boomerang Island Waterfowl use

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Photo E.1: Pool 9 Island Constructed 1995

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Photo E.2: POOL 9 ISLAND

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Photo F.1: Polander Lake, Stage 1, Island 2 Constructed 1994

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Photo G.1: Willow Island, Pool 10 Constructed 1995

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Photo G.2: Willow Island Berm

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Photo H.1: Pool 8, Phase II Constructed 1999 Stoddard Bay

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Photo H.2: Hydraulic dredging of sand

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Photo H.3: Incorporating island remnants into new shoreline

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Photo H.4: Hydraulic Placement of Fines

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Photo H.5: Rock Sill B Stoddard Bay

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Photo H.6: Rock Sill B overtopped

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Photo H.7: Notch in Rock Sill A

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St. Paul District

Photo H.8: Vegetative response in Stoddard Bay

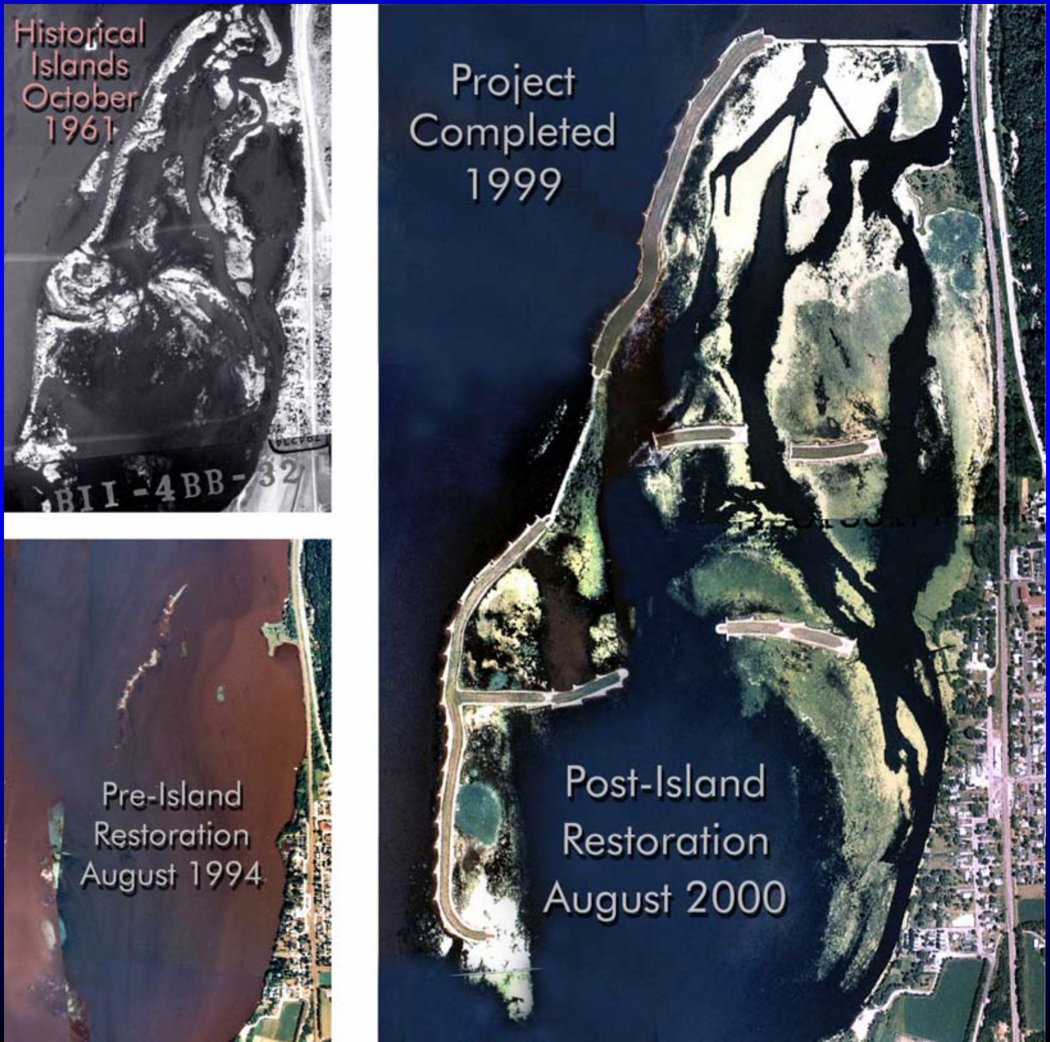

Photo H.9: Slingshot Island stable after 2001 flood

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Photo H.10: Erosion of turtle nesting mound on Slingshot Island occurred during the 2001 flood

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Photo H.11: Rock Mound

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Photo H.12: Topsoil Erosion, Slingshot Island

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Photo H.13: Remnant island, Stoddard Bay

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Photo H.14: Pool 8, Phase II. Pelicans on rock seed island.

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Photo H.15: Rock Sill B

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Photo I.1: Polander Lake Constructed 2000

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Photo I.2: Loafing structure anchored with rock

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St. Paul District

Photo I.3: Groins

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Photo I.4: Erosion of top of island due to 2001 flood

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Photo I.5: Scalloping around groin occurred during the 2001 flood

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St. Paul District

Photo I.6: Erosion of sand and fines occurred during the 2001 flood

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St. Paul District

Photo I.7: Benching due to wave action during the 2001 flood

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Photo I.8: A breach formed due to overtopping during the 2001 flood.

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Photo I.9: Polander Lake shoreline

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Photo I.10: Interior wetland

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Photo I.11: Polander Lake prairie grasses

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Photo I.12: Polander Lake loafing structures

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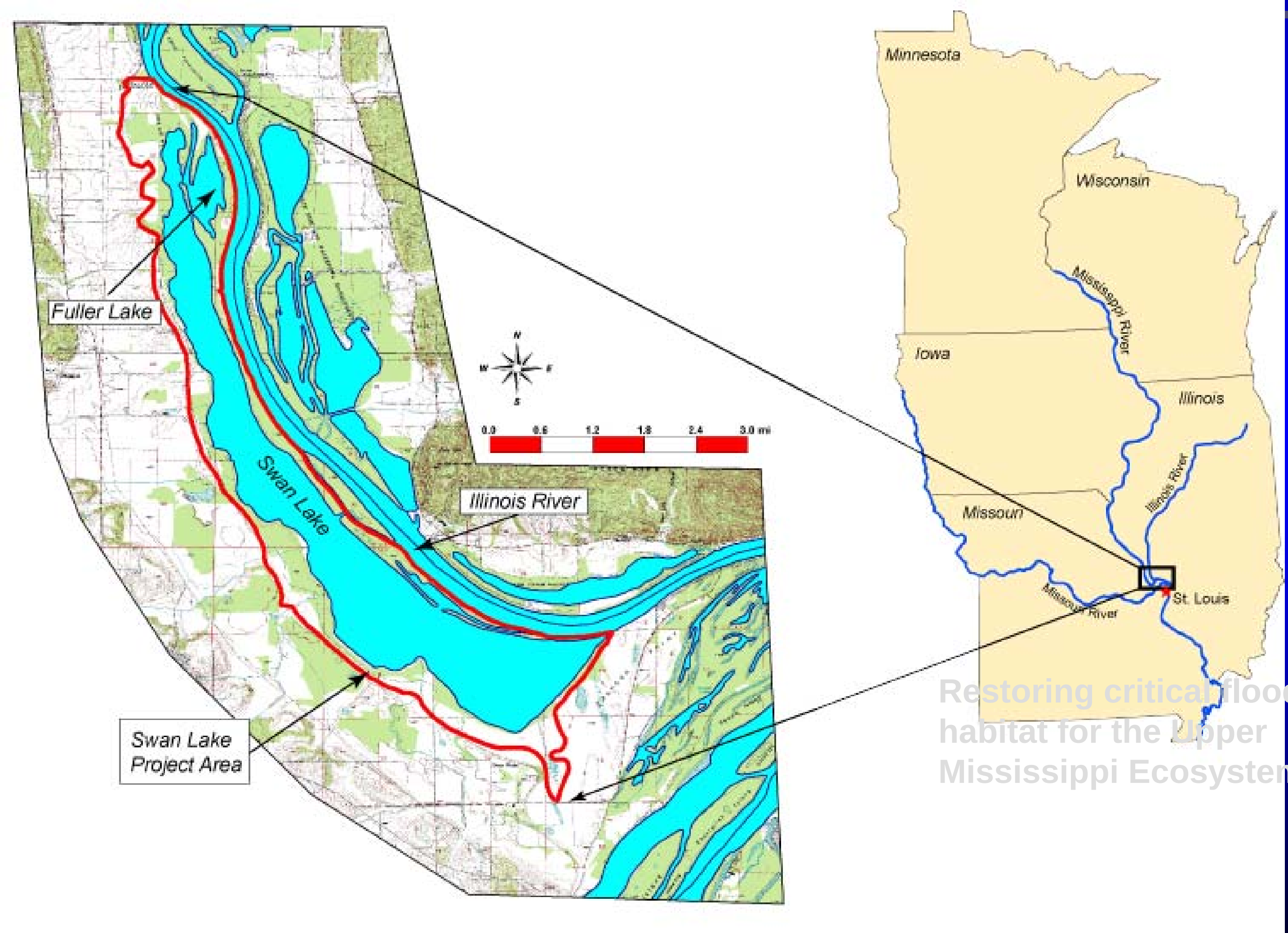
St. Paul District

Photo J.1: Swan Lake, Illinois River Plan View



Restoring critical floodplain habitat for the Upper Mississippi Ecosystem

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of Engineers
St. Paul District

Photo J.2: Aerial View of Swan Lake Project, Looking North

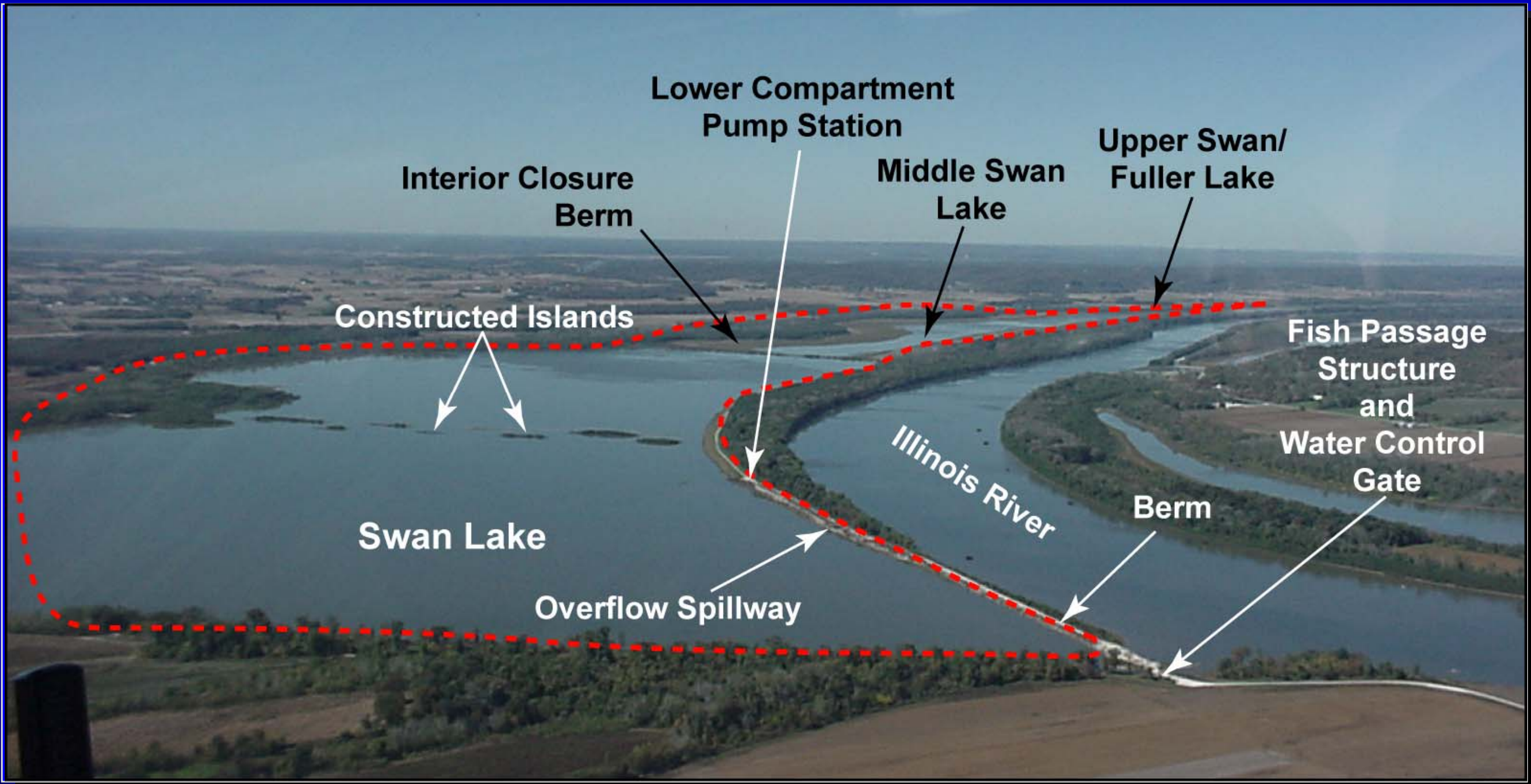

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Photo J.3: Swan Lake Islands, Illinois River

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Photo J.4: Swan Lake Islands, Illinois River

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Photo K.1: Spring Lake Islands, Pool 5

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Photo K.2: Spring Lake Islands, Pool 5

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Photo K.3: Spring Lake Islands, Pool 5, Vanes

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Photo L.1: Peroria Lake Islands, Illinois River

Photo N.1: Pool 11 Islands, Sunfish Lake

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Photo K.1: Grand Endcampment Vanes used to stabilize beach

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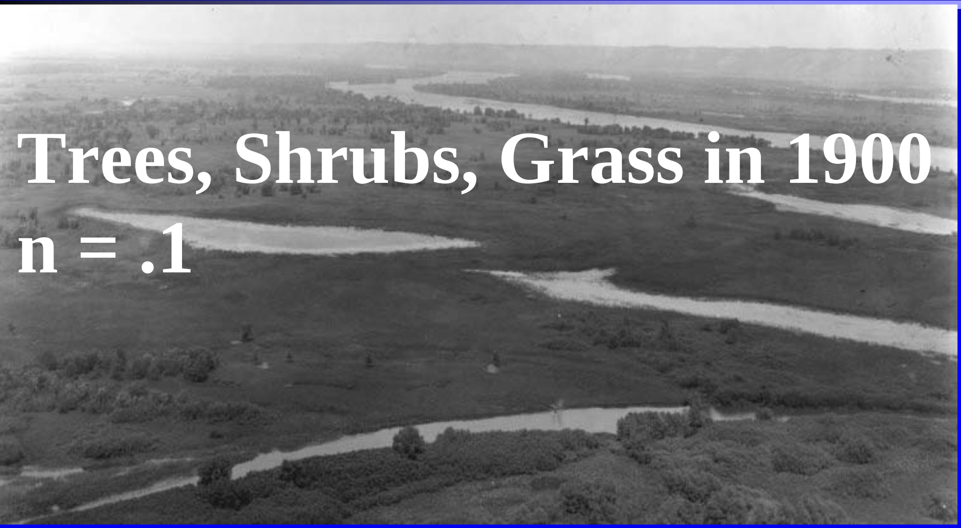

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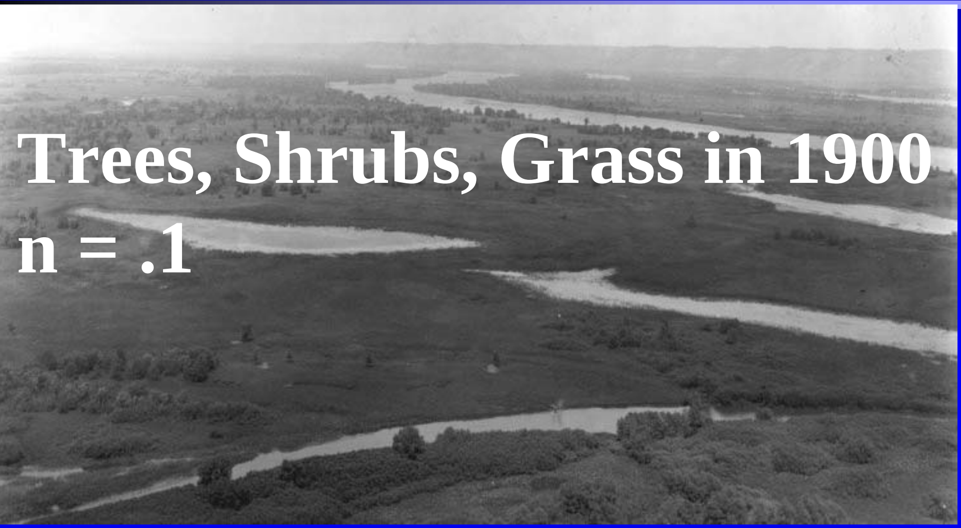
Photo K.2: Weaver Bottoms. Floodplain vegetation and roughness changes.



Physical Stresses:
Q floodplain ↑
Secondary Channel Erosion

Biological Effects:
Isolated Floodplain Habitat ↓

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Pool 8, Phase 3 Layout

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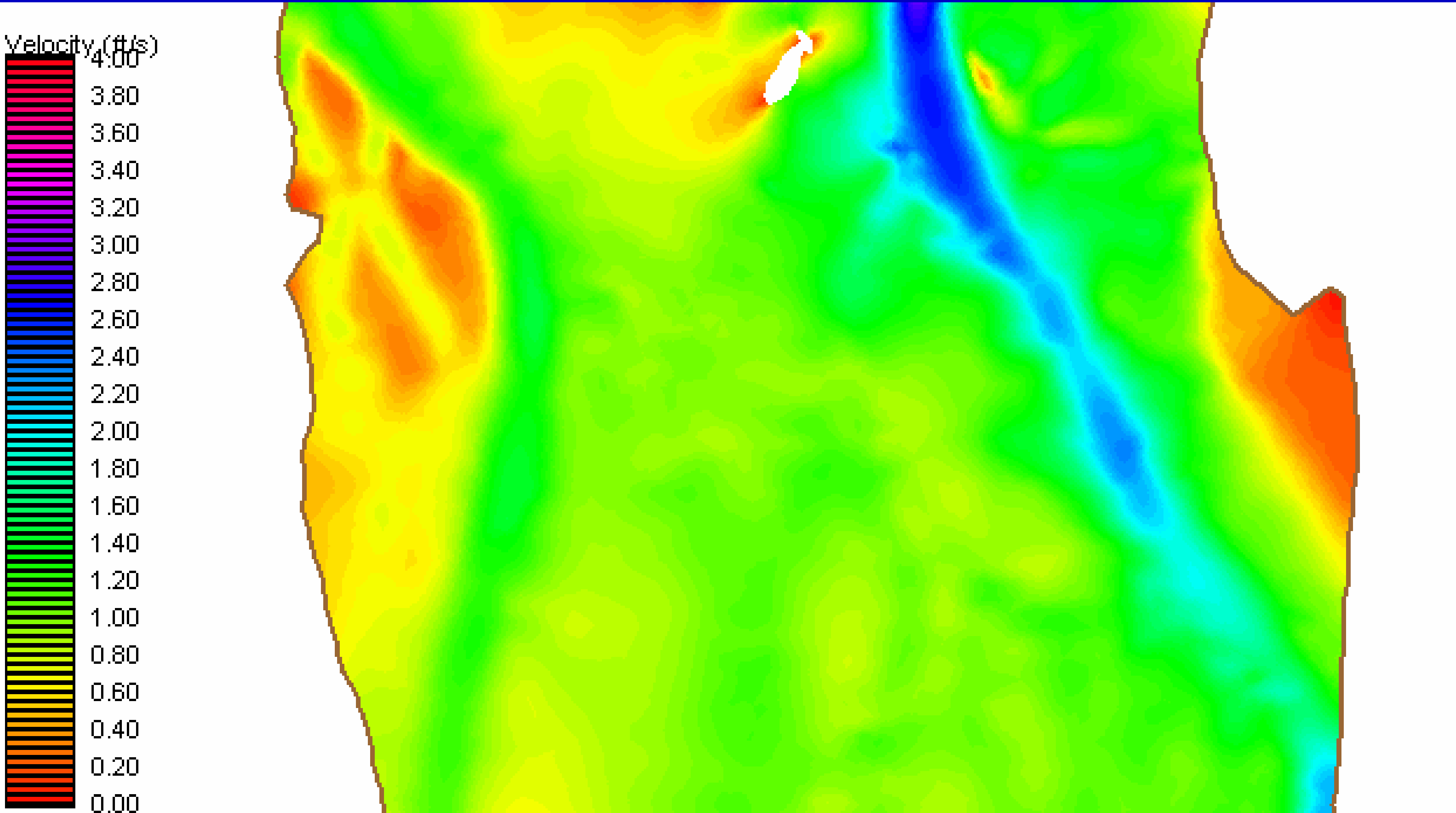
Pool 8, Phase 3 Existing Conditions Velocity



Pool 8, Phase 3 Proposed Conditions Velocity

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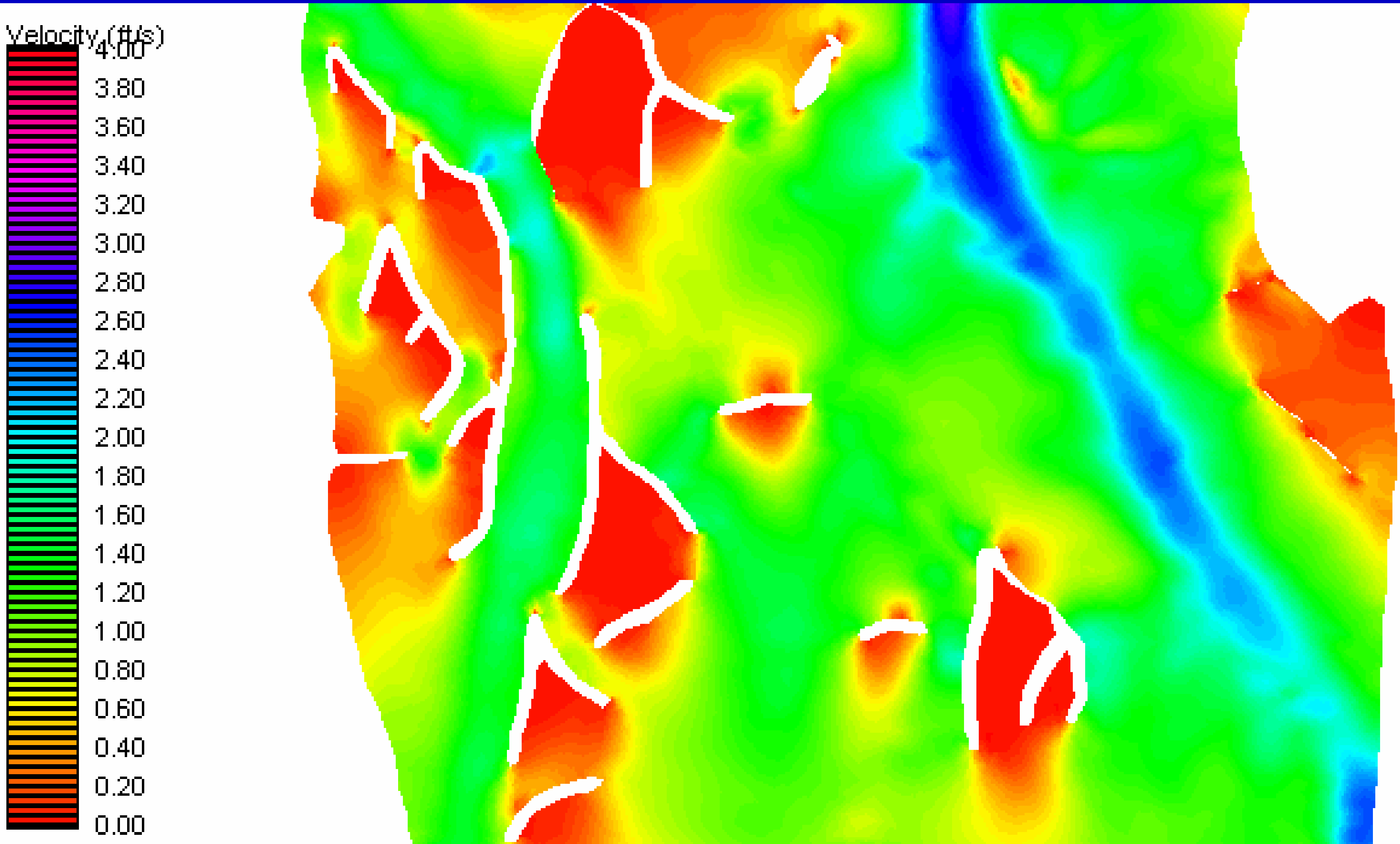

Pool 8 Existing – North Section

Q = 50,000 cfs

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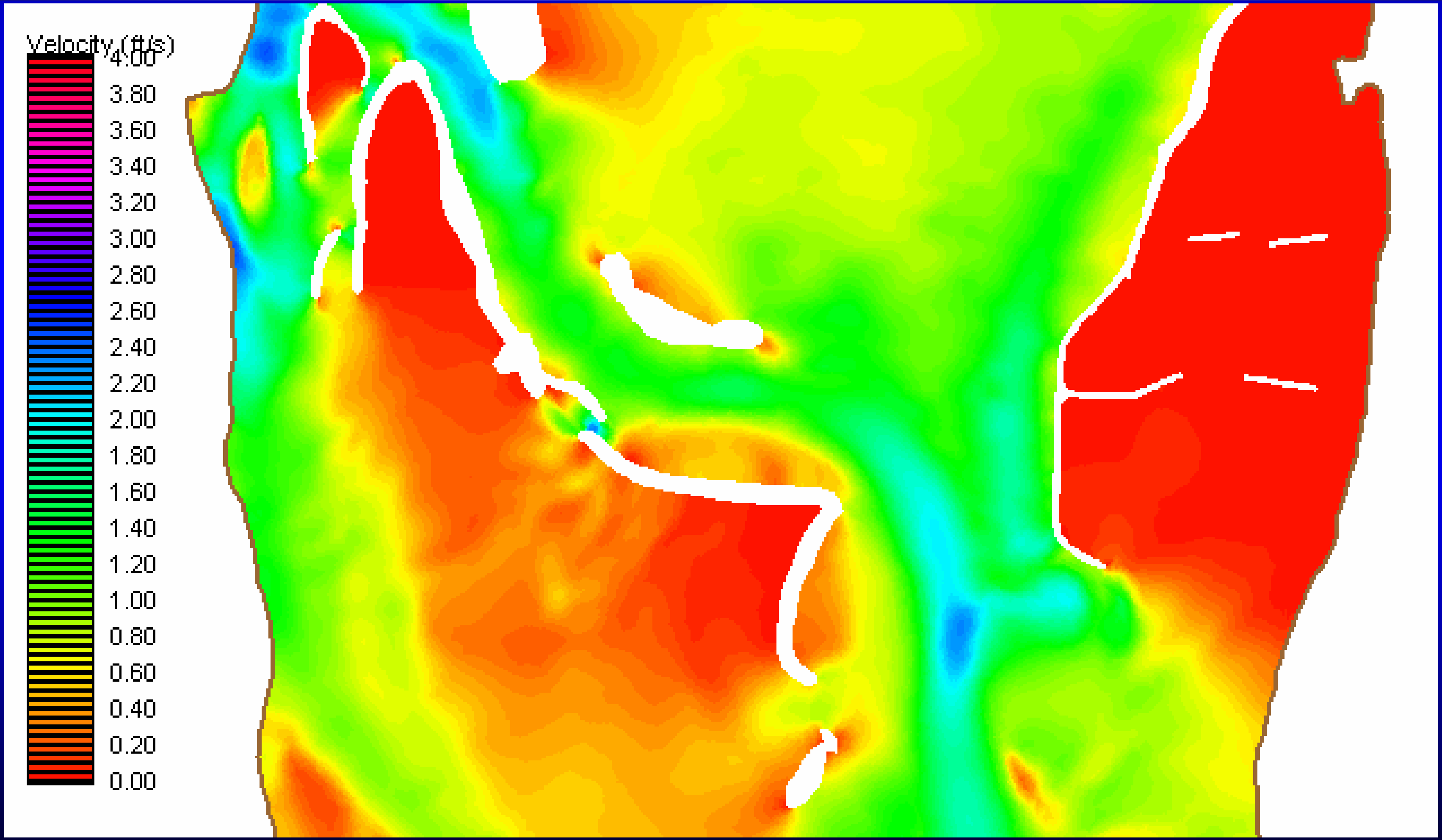

Pool 8 Existing – North Section
Q = 80,000 cfs

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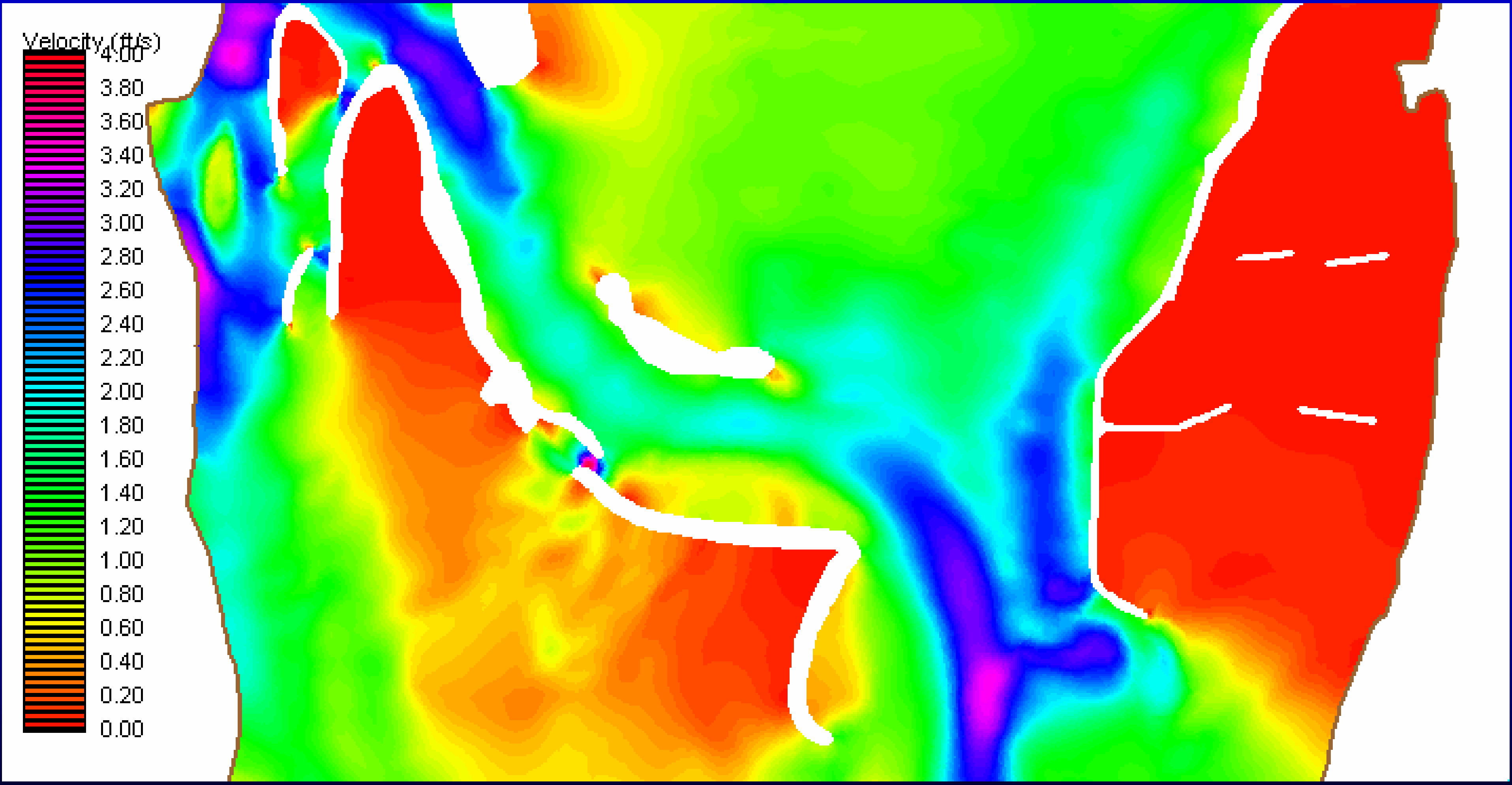

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Red Oak Island Roots

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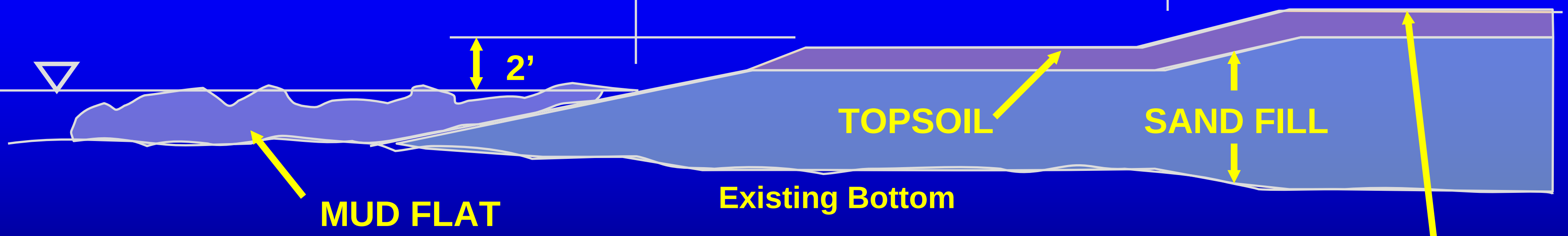
ISLAND CROSS SECTION

HABITAT →	AQUATIC PLANTS & MUDFLATS	WILLOWS & BEACH	TREES & GRASSES
DIMENSION →	MUDFLAT WIDTH IS 20 TO 200 FEET	BERM WIDTH IS 30 TO 60 FEET	TOP WIDTH IS 30 TO 80 FEET



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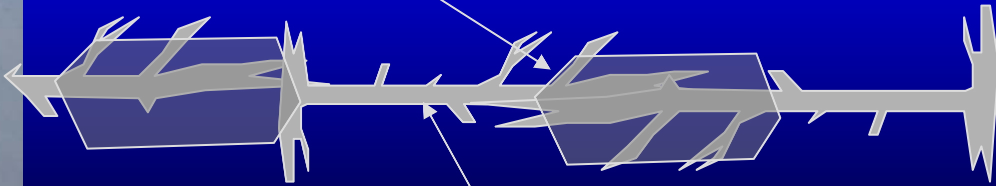
ISLAND TYPES



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SHORELINE STABILIZATION

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HABITAT PROJECT DESIGN

- Multi-discipline Teams: Project Design Must Evolve With River Sciences.
- Restoration Concept: Restore Form and Function to Restore Sustainable Habitat.
- New Projects: Based on Sound Engineering, Past Lessons, & New Creativity.

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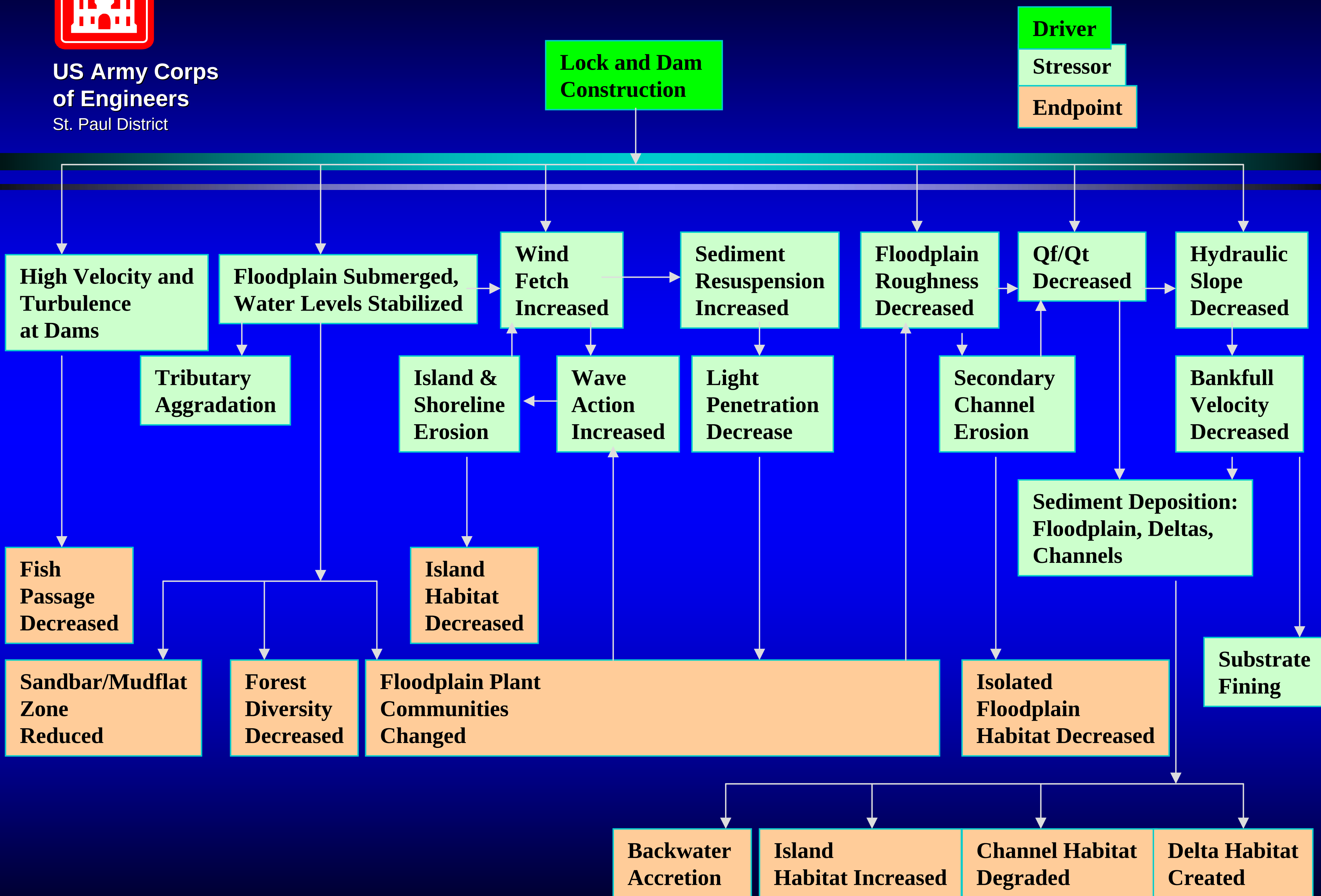


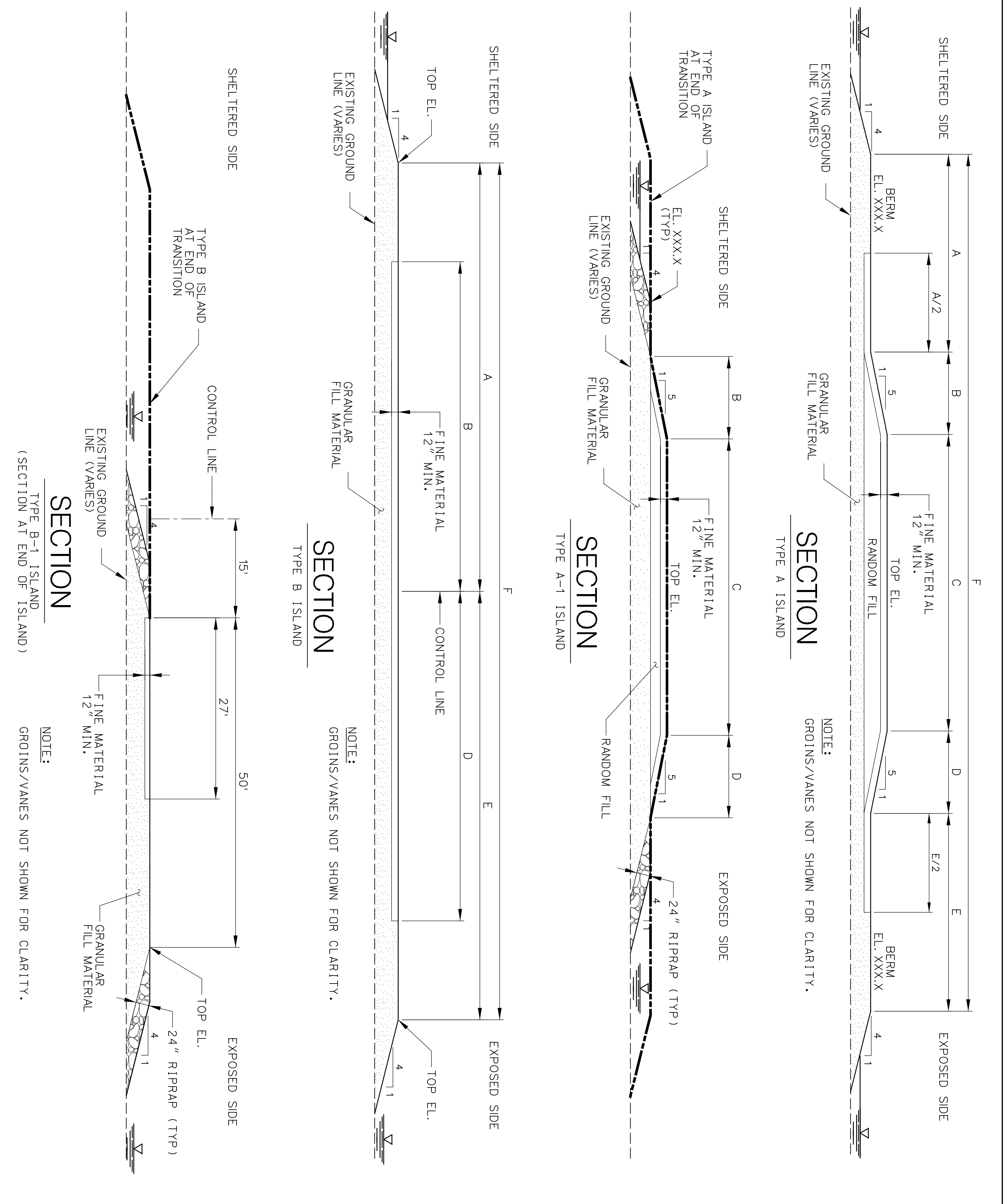
Jon S. Hendrickson,02/26/03

UPPER MISSISSIPPI RIVER SYSTEM
ENVIRONMENTAL MANAGEMENT PROGRAM
DESIGN HANDBOOK

CHAPTER 9

ISLANDS

APPENDIX E
STANDARD DETAILS



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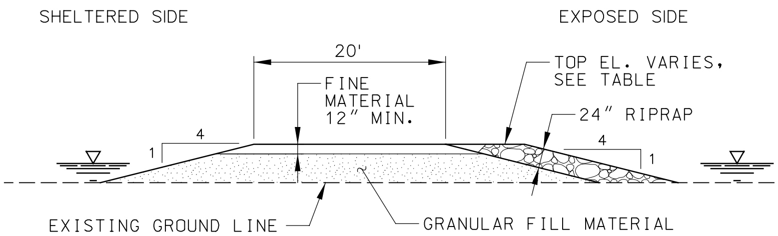
ED-D	DESIGNED BY: LKT/JJF	DATE:
	CHECKED BY: JSH	SEPTEMBER 2004
ED-H	DESIGNED BY: JSH/KAL	CADD FILE NAME:
	CHECKED BY: JSH	EMP_StandardDetails

HABITAT REHABILITATION & ENHANCEMENT PROGRAM
ISLAND DESIGN MANUAL
STANDARD DETAILS

ISLAND TYPES A & B

PLATE 1

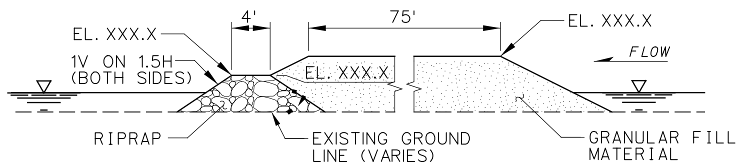
SHEET XX OF XX



SECTION

TYPE C ISLAND

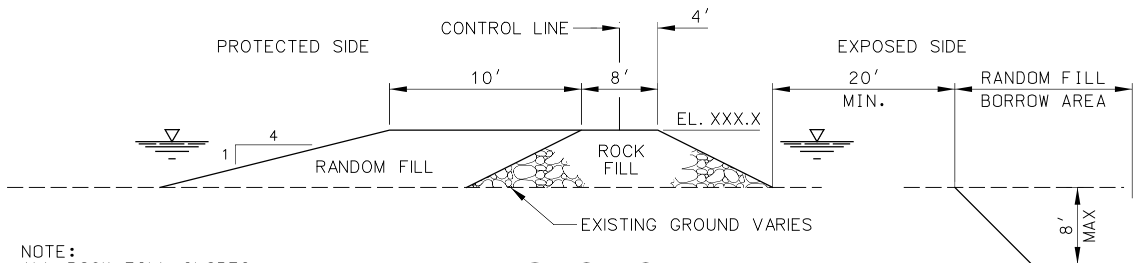
10 0 10 20
SCALE IN FEET



SECTION

TYPE D - SEED ISLAND

10 0 10 20
SCALE IN FEET

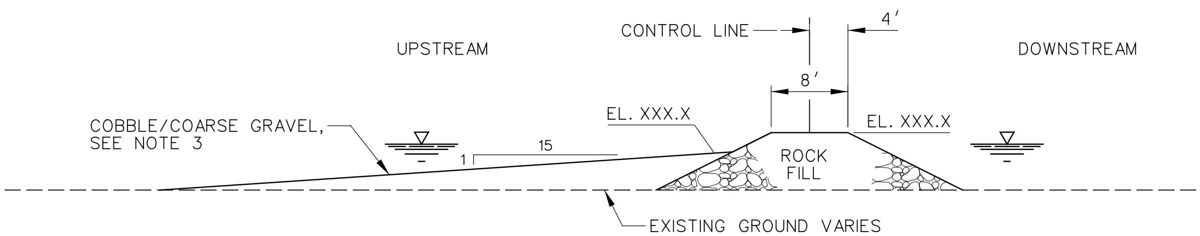


NOTE:
ALL ROCK FILL SLOPES SHALL BE 1V:2H.

SECTION

TYPE E

10 0 10 20
SCALE IN FEET



NOTE:
ALL ROCK FILL SLOPES SHALL BE 1V:2H.

SECTION

TYPE F
FISH SPAWNING HABITAT

10 0 10 20
SCALE IN FEET

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	CHECKED BY: JSH	SEPTEMBER 2004
ED-H	DESIGNED BY: JSH/KAL	CADD FILE NAME:
	CHECKED BY: JSH	EMP_StandardDetails

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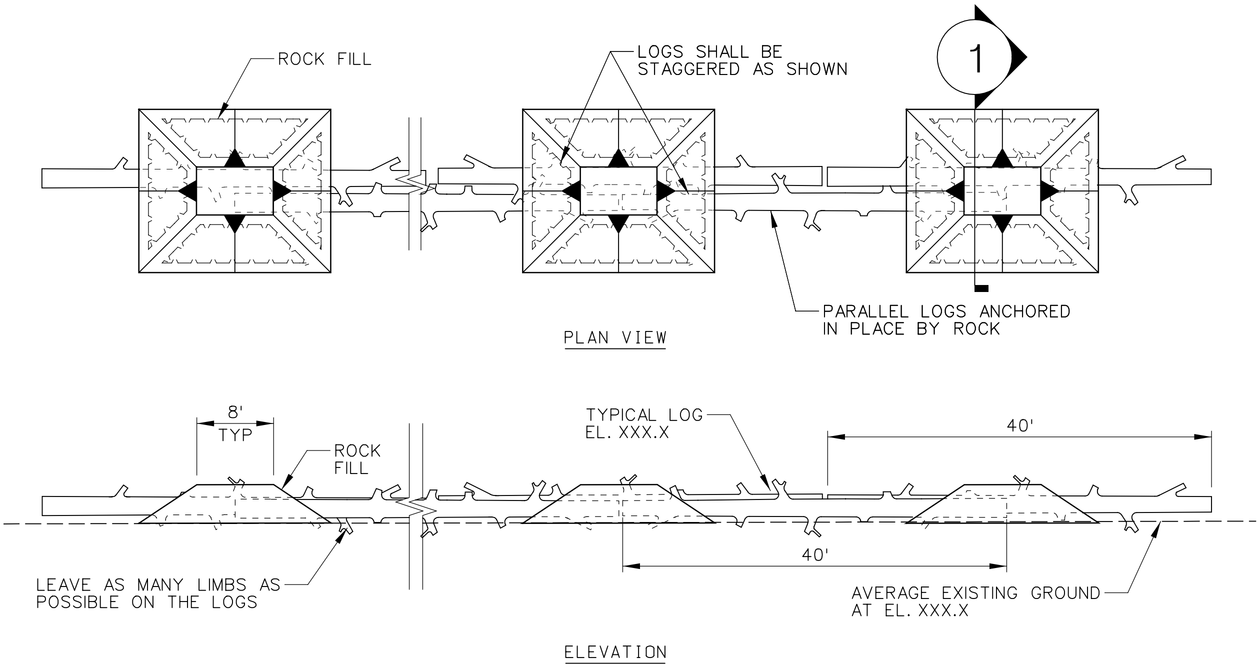
HABITAT REHABILITATION & ENHANCEMENT PROGRAM
ISLAND DESIGN MANUAL
STANDARD DETAILS

ISLAND TYPES C, D, E & F

PLATE 1

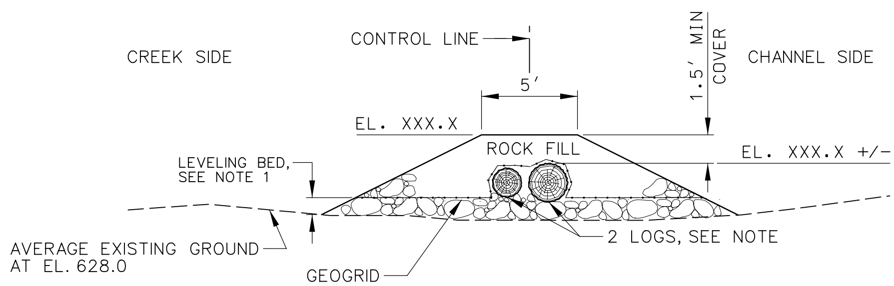
SHEET XX OF XX



TYPICAL DETAIL

ROCK/LOG ISLAND

10 0 10 20
SCALE IN FEET



1 SECTION

TYPICAL ROCK/LOG ISLAND

5 0 5 10
SCALE IN FEET

NOTE:

LOGS SHALL BE 40' LONG AND 2' MIN. DIAMETER AT BASE. TRIM LIMBS AS NECESSARY TO ALLOW LOG PLACEMENT TO THE CORRECT ELEVATION. A ROCK FILL LEVELING BED SHALL BE USED TO BRING LOGS TO THE DESIGN ELEVATION. ROCK THICKNESSES WILL VARY.

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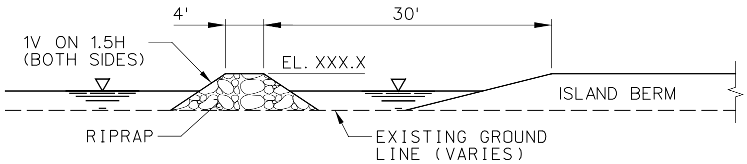
St. Paul District

ED-D	DESIGNED BY: LKT/JJF	DATE:
	CHECKED BY: JSH	SEPTEMBER 2004
ED-H	DESIGNED BY: JSH/KAL	CADD FILE NAME:
	CHECKED BY: JSH	EMP_StandardDetails

HABITAT REHABILITATION & ENHANCEMENT PROGRAM
ISLAND DESIGN MANUAL
STANDARD DETAILS
ROCK/LOG ISLAND

PLATE 1

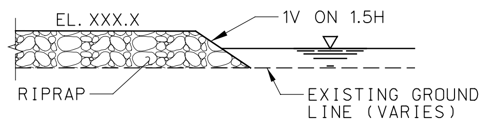
SHEET XX OF XX



SECTION

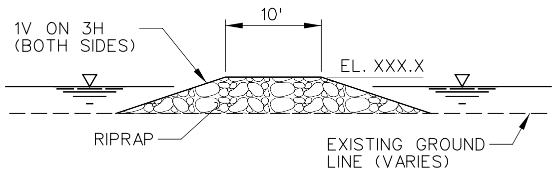
ROCK MOUND ALONG ISLAND

10 0 10 20
SCALE IN FEET



LONGITUDINAL SECTION

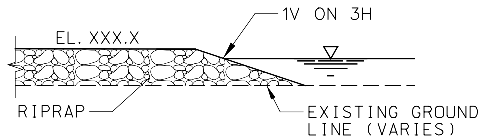
THRU ROCK MOUND AT END (TYP)



SECTION

ROCK SILL

10 0 10 20
SCALE IN FEET



LONGITUDINAL SECTION

THRU ROCK SILL AT END (TYP)

US Army Corps of Engineers
St. Paul District

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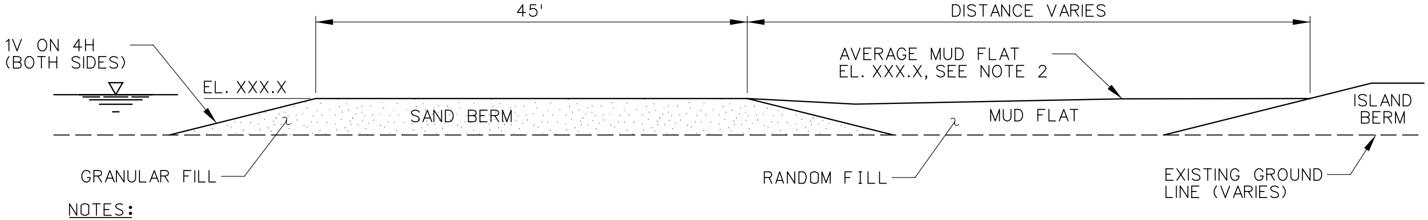
HABITAT REHABILITATION & ENHANCEMENT PROGRAM
ISLAND DESIGN MANUAL
STANDARD DETAILS

ROCK MOUND AND SILL

PLATE 1

SHEET XX OF XX



NOTES:

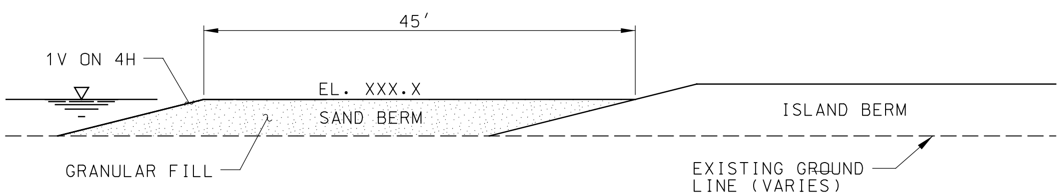
1. THIS SECTION DENOTES FINISHED DIMENSIONS AND ELEVATIONS. DIMENSIONS AND ELEVATIONS NECESSARY DURING CONSTRUCTION TO MEET SEDIMENT RETENTION NEEDS SHALL BE DETERMINED BY THE CONTRACTOR.

2. MUDFLAT MAY VARY BETWEEN EL. XXX.X AND EL. XXX.X. MUDFLATS SHALL SLOPE TOWARD SAND BERMS AND AWAY FROM ISLAND AND TURTLE NESTING STRUCTURES.

TYPICAL SECTION

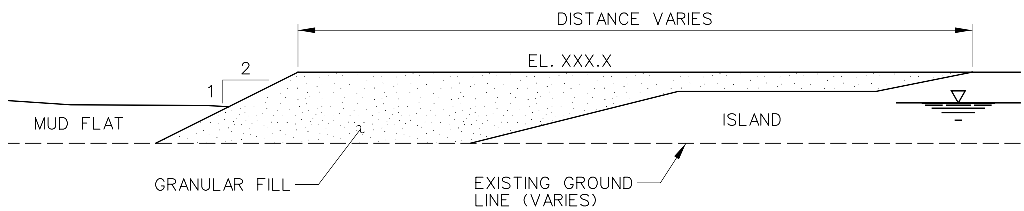
THRU SAND BERM & MUD FLAT

10 0 10 20
SCALE IN FEET



SECTION

TYPICAL SAND FLAT



TYPICAL SECTION

TURTLE NESTING STRUCTURE

10 0 10 20
SCALE IN FEET

US Army Corps of Engineers
St. Paul District

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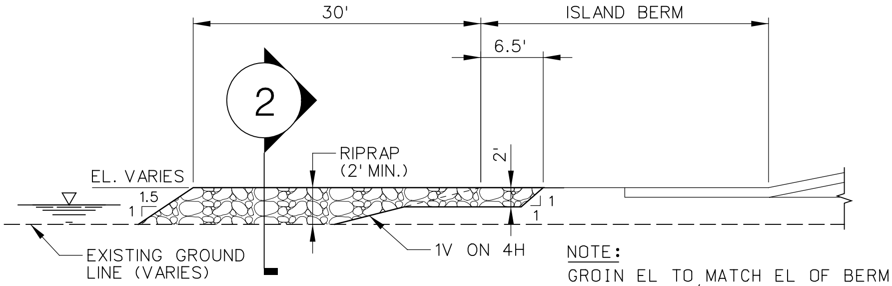
ISLAND DESIGN MANUAL
STANDARD DETAILS
MUD/SAND FLATS AND
TURTLE NESTING MOUND

PLATE 1

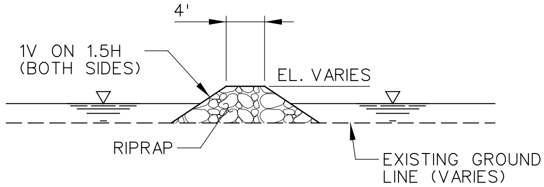
SHEET XX OF XX



ELEVATION

TYPICAL ROCK GROIN

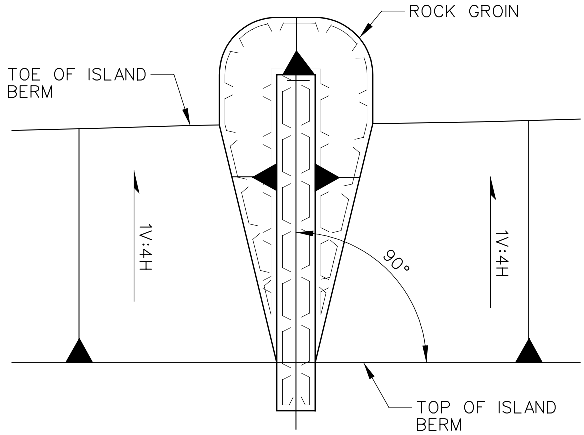
10 0 10 20
SCALE IN FEET



2 SECTION

TYPICAL ROCK GROIN/VANE

10 0 10 20
SCALE IN FEET



PLAN

TYPICAL ROCK GROIN

10 0 10 20
SCALE IN FEET

US Army Corps
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St. Paul District

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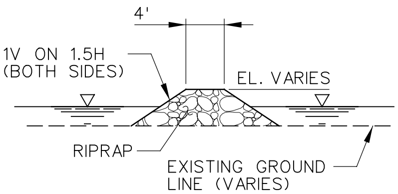
HABITAT REHABILITATION & ENHANCEMENT PROGRAM
ISLAND DESIGN MANUAL
STANDARD DETAILS
ROCK GROIN

PLATE 1

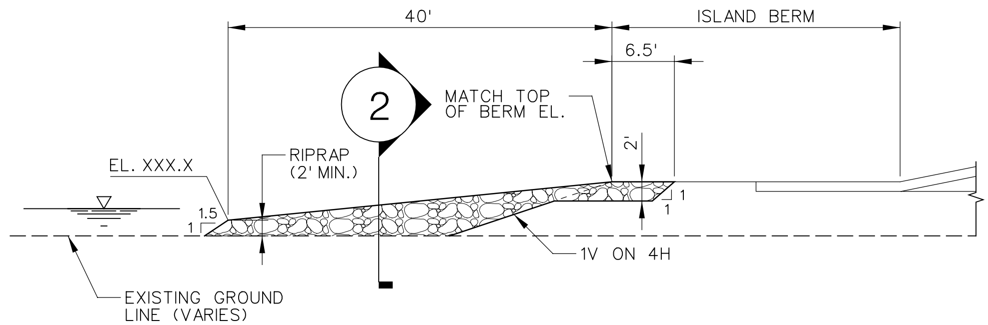
SHEET XX OF XX



2 SECTION

TYPICAL ROCK GROIN/VANE

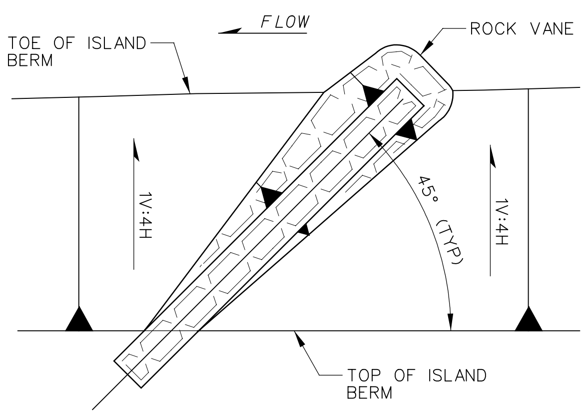
10 0 10 20
SCALE IN FEET



ELEVATION

TYPICAL ROCK VANE

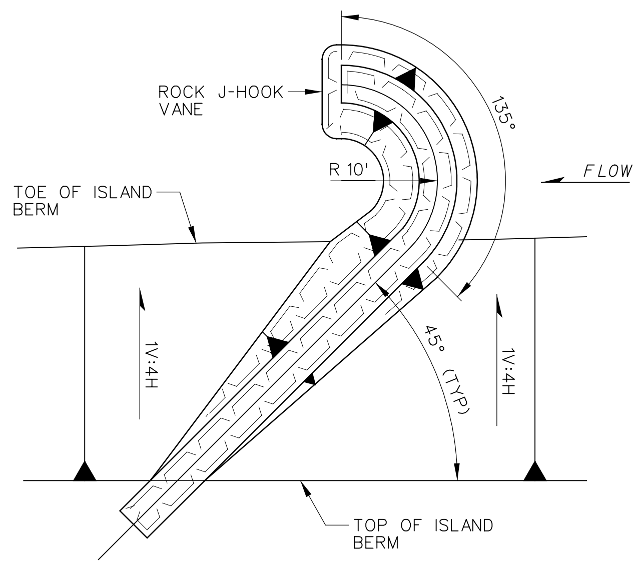
10 0 10 20
SCALE IN FEET



PLAN

TYPICAL ROCK VANE

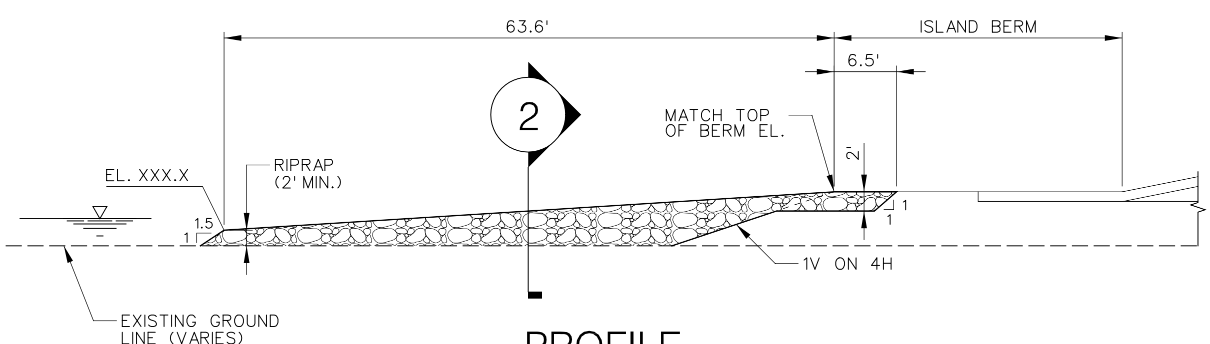
10 0 10 20
SCALE IN FEET



PLAN

TYPICAL ROCK J-HOOK VANE

10 0 10 20
SCALE IN FEET



PROFILE

TYPICAL J-HOOK ROCK VANE

10 0 10 20
SCALE IN FEET

US Army Corps of Engineers
St. Paul District

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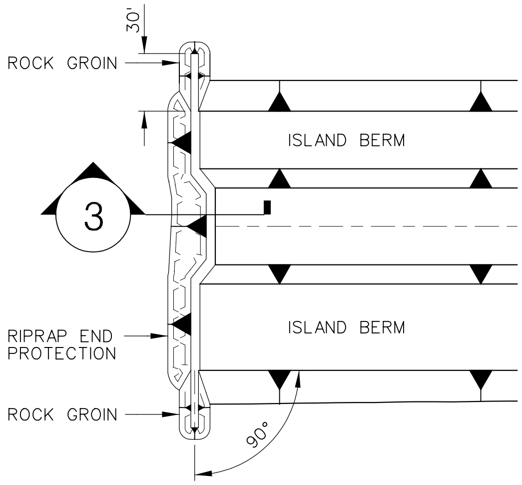
ISLAND DESIGN MANUAL
STANDARD DETAILS

ROCK VANES

J-HOOK AND STANDARD

PLATE 1

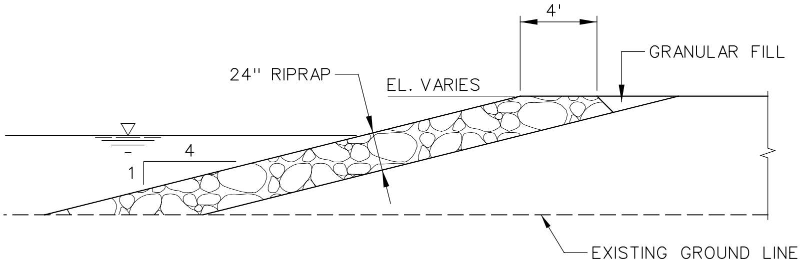
SHEET XX OF XX



PLAN

RIPRAP END PROTECTION – FLAT

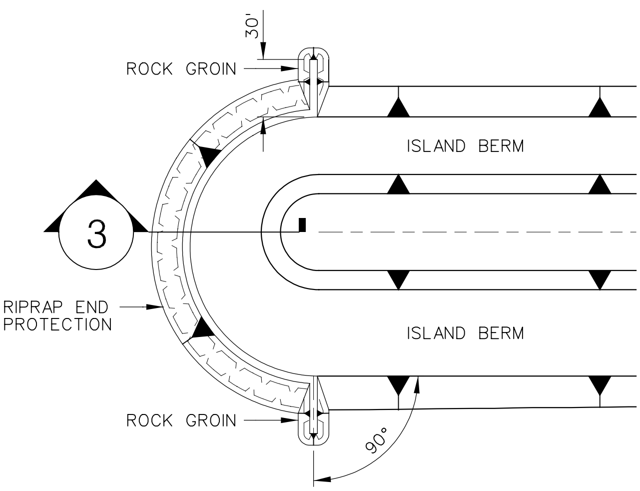
50 0 50 100
SCALE IN FEET



3 SECTION

ISLAND RIPRAP END PROTECTION/
BANK STABILIZATION

5 0 5 10
SCALE IN FEET



PLAN

RIPRAP END PROTECTION – ROUND

50 0 50 100
SCALE IN FEET

US Army Corps
of Engineers
St. Paul District

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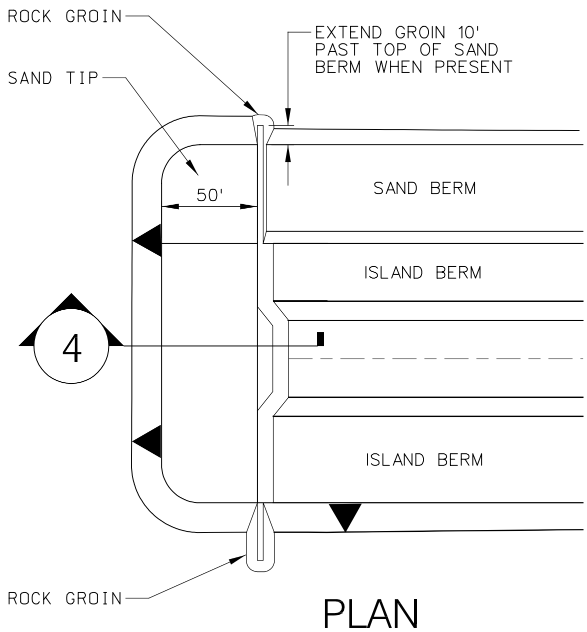
HABITAT REHABILITATION & ENHANCEMENT PROGRAM
ISLAND DESIGN MANUAL
STANDARD DETAILS
ISLAND END PROTECTION
PLAN AND SECTION

PLATE 1

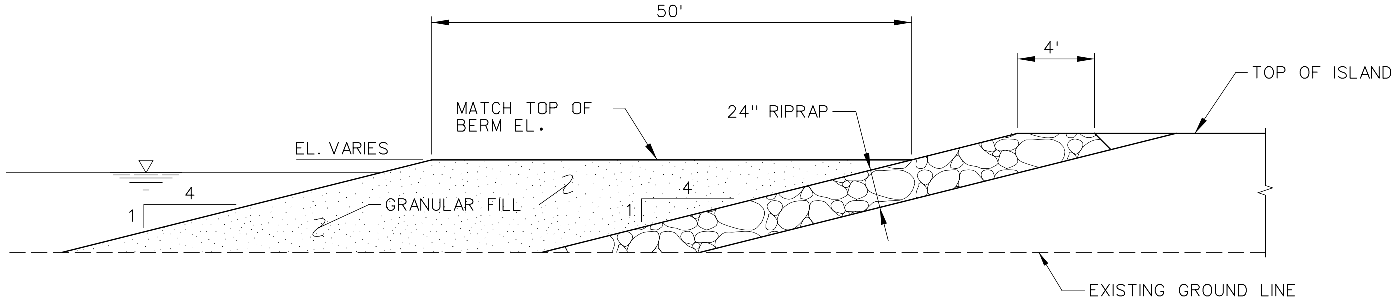
SHEET XX OF XX



PLAN

RIPRAP END PROTECTION
WITH SAND TIP

50 0 50 100
SCALE IN FEET



4 SECTION

ISLAND RIPRAP END PROTECTION/
BANK STABILIZATION AND SAND TIP

5 0 5 10
SCALE IN FEET

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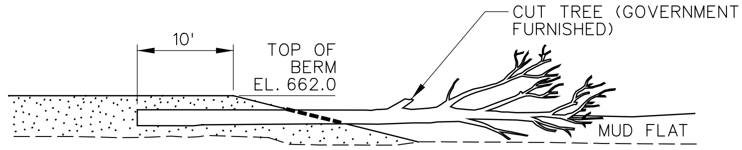
HABITAT REHABILITATION & ENHANCEMENT PROGRAM
ISLAND DESIGN MANUAL
STANDARD DETAILS

ISLAND SAND TIP

PLATE 1

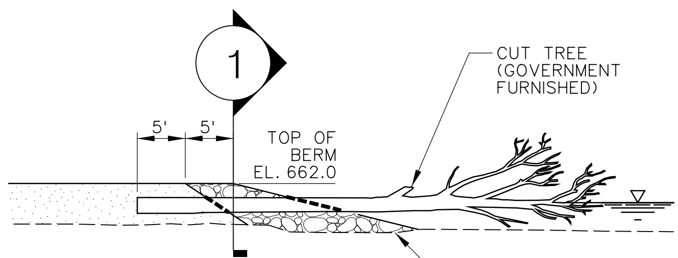
SHEET XX OF XX



SECTION

TYPE 1
WILDLIFE LOAFING STRUCTURE

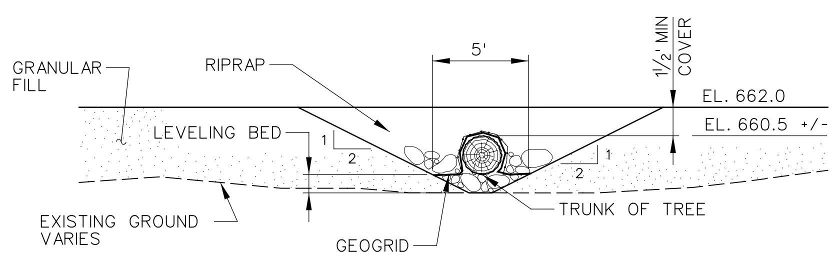
10 0 10 20
SCALE IN FEET



SECTION

TYPE 2
WILDLIFE LOAFING STRUCTURE

10 0 10 20
SCALE IN FEET



1 SECTION

WILDLIFE LOAFING STRUCTURE ANCHORAGE

5 0 5 10
SCALE IN FEET

US Army Corps of Engineers
St. Paul District

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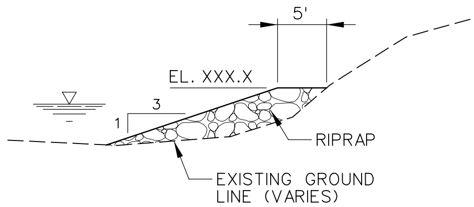
ISLAND DESIGN MANUAL
STANDARD DETAILS
WILDLIFE LOAFING STRUCTURES

PLATE 1

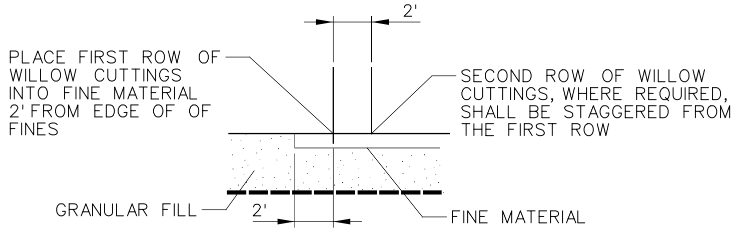
SHEET XX OF XX



TYPICAL SECTION

RIPRAP BANK PROTECTION

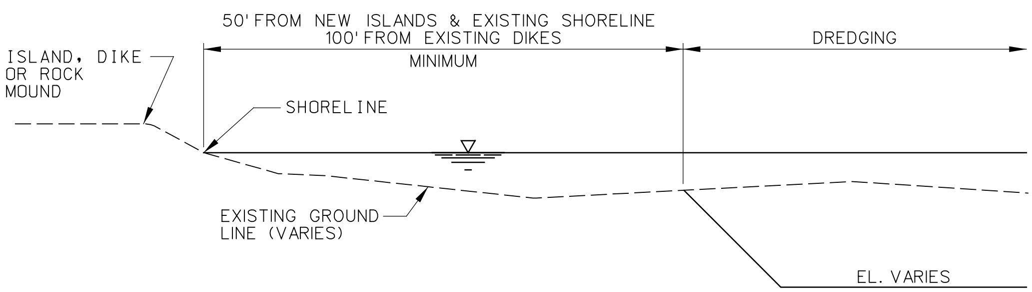
10 0 10 20
SCALE IN FEET



SECTION

WILLOW PLANTING

5 0 5 10
SCALE IN FEET



SECTION

DREDGING

10 0 10 20
SCALE IN FEET

US Army Corps of Engineers
St. Paul District

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HABITAT REHABILITATION & ENHANCEMENT PROGRAM
ISLAND DESIGN MANUAL
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MISCELLANEOUS DETAILS

PLATE 1

SHEET XX OF XX