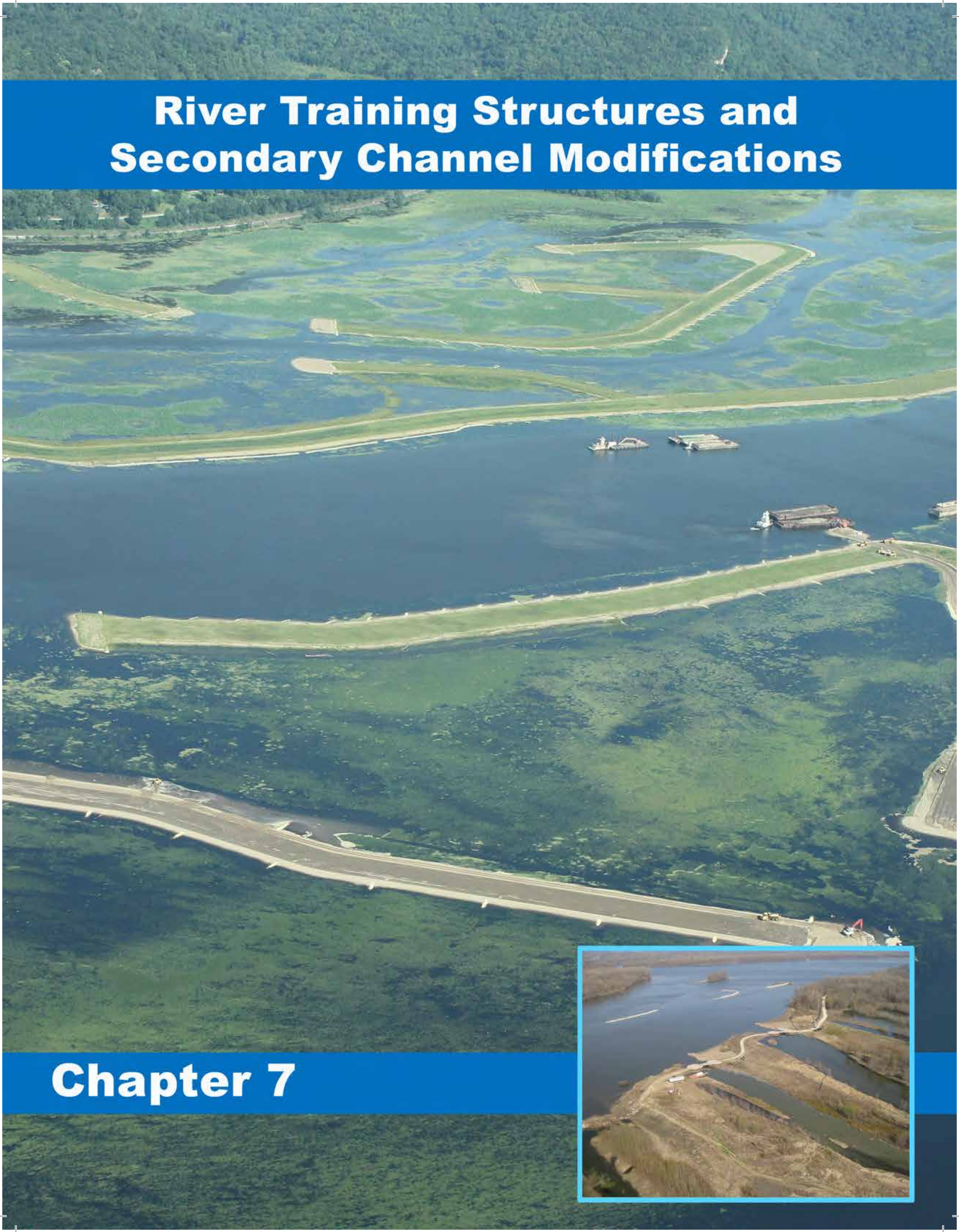
River Training Structures and Secondary Channel Modifications



Chapter 7

UPPER MISSISSIPPI RIVER RESTORATION ENVIRONMENTAL MANAGEMENT PROGRAM ENVIRONMENTAL DESIGN HANDBOOK

CHAPTER 7

RIVER TRAINING STRUCTURES AND SECONDARY CHANNEL MODIFICATIONS

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CHAPTER 7

RIVER TRAINING STRUCTURES AND SECONDARY CHANNEL MODIFICATIONS

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RIVER TRAINING STRUCTURES AND SECONDARY CHANNEL MODIFICATIONS

The US Army Corps of Engineers (Corps) continues to use river training structures 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 become more environmentally conscious, we continue to develop intuitive river training structure designs to maximize benefits for both navigation and river restoration.

A. PRE-INUNDATION CONDITIONS

Human-induced physical modifications of the Upper Mississippi River System (UMRS) channel began as early as 1832 with removal of snags to facilitate steamboat travel (Burke and Robins, 1979). In 1878, Congress authorized a program to provide a navigation channel 4 ½ foot deep in the Upper Mississippi River. This authorization included channel deepening and construction of river training structures, specifically, closing dams, wing dams and rock revetments. These structures continue to concentrate the river flow and force it to scour out a deeper navigation channel. They also reduce bankline erosion on outside bends of the river.

As subsequent Congressional authorizations raised the depth of the UMRS navigation channel, the Corps' use of river training structures, along with dredging, continues to be the most economic tools for maintaining the current 9-foot operating depth.

B. RESOURCE PROBLEMS

In all the regulated sections of the UMRS, the construction and maintenance of locks and dams have altered physical habitat for fish, invertebrates, and plants by changing stream flow from free-flowing to impounded, and altering the natural hydrology and the physical structure of the channel. As a result, the river has changed from a meandering, flowing system, which periodically overran its banks and floodplain, to a series of impoundments connected by dredged channels where the Corps controls the stream flow and water levels. The impoundments changed the physical structure of the river, the diversity of aquatic habitats, and water quality.

Impoundments reduce the velocity and warm the water in the pools. Reduced velocity causes sediment to settle, changing the composition of the substrate on the bottom of impoundments to fine-grained material (sand and silt). Nutrients and contaminants associated with sediment particles are concentrated in the bottom sediments of the pools (Stark, et al., 2000).

Today's URMS pools, regulated by the series of locks and dams, have shown significant changes exemplified by the loss of islands in the lower pool, and filling of backwaters with sediment.

The following are some river conditions challenging engineers and biologists to develop sound solutions to today's navigation and river restoration missions.

1. **Meandering River Channel.** As a typical alluvial channel the Mississippi River likes to meanders back and forth along its floodplain, constantly realigning itself. This natural meandering process is the river's attempt to restore balance in the system by eroding its banks, and reducing the overall energy in the system. As the Mississippi River travels south, sinuosity increases linearly, as velocities increase. The bends can create a turning challenge to 1200 foot barges trying to navigate in strong currents, especially when passing a barge going the opposite direction. The Corps' channel maintenance is also tested at these bend areas due to shoaling in the slack area, or inside of the bend, and eroding or shifting channel on the outside of the bend.

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.

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.

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.

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. Sedimentation/Biological Concerns. Sedimentation is a naturally occurring phenomenon. Traditionally, it is managed through the use of river training structures and 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 biologists look favorably on both environments, 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.

6. Homogeneous Environments. One long, deep river creates a homogeneous unhealthy environment. 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.

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 its tremendous energy. While these stabilization methods have held lateral erosion or meandering movement of the river in check, 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.

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 US Army Corps of Engineers, St. Louis District web site, http://mvs-wc.mvs.usace.army.mil/arec/ "Applied River Engineering Center."

Excessive bankline erosion and overbank scour are phenomenon caused by river conditions existing 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.

C. RESOURCE OPPORTUNITIES

Despite some of the negative impacts associated with river training structures on river morphology, several aspects of their physical impacts on the local ecology give promise to habitat restoration on the UMR.

The aquatic community found near a training structure is relatively diverse, owing to the range of available habitat types within a comparatively small area. The St. Louis District contracted a study which analyzed invertebrate populations on the dikes and in the surrounding riverbed to determine if chevron dikes were providing macroinvertebrate habitat. The macroinvertebrate assemblages were compared between the interior dike rock, exterior dike rock, interior soft substrate, and the surrounding soft substrate. No unionids (mussels) were found due to previous open water dredge disposal in the area. However, the dikes and protected areas behind dikes were providing habitat for invertebrates and fish. Diversity and taxonomic richness was higher on dikes than in the surrounding soft substrates in all three years of the study (Ecological Specialists, Inc. 1997).

Sandheinrich and Atchison (1986) found dike (i.e., wingdams) fields provide a varied range of depths, substrates, and currents that increase habitat complexity and affect fish distributions and community diversity. The fish communities associated with dikes are diverse and may harbor more species than any other habitat within the main channels.

In addition, the St. Louis District is developing innovative designs for river training structures and modifications, which primarily serve to help maintain the navigation channel, but which can also enhance the river's habitat diversity when properly designed. These structures can alter hydrodynamic conditions, sediment transport regimes, water depth diversity, and habitat conditions.

D. HABITAT REHABILITATION AND ENHANCEMENT PROJECT (HREP) OBJECTIVES[1]

Harnessing the positive benefits from training structures fits nicely with the EMP goals and objectives outlined in the 2010 EMP Report to Congress (USACE, 2010). These structures' ability to alter hydrology and their physical character contribute to the overall diversity and conditions aquatic animals seek out for shelter and food.

Engineers and biologist who know how river training structures alter a river's physical dynamics can use this to design project features such as island creation and protection, scour holes, and slack water habitats. Section E describes various training structures, their application and benefits to habitat manipulation.

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[1] For a detailed explanation of the overall EMP vision, goals, and objectives, see Chapter 2, *Habitat Rehabilitation and Enhancement Projects*.

The 2010 EMP Report to Congress first described how river training structures meet the UMRS Environmental Objectives, specifically:

- Improve fish habitat and water quality by altering inflows and diversifying substrate thickness
- Stabilize eroding channels
- Reduce sediment load to backwaters by reducing flow velocities
- Maintain water temperature and provided rock substrate

E. RESTORATION OPPORTUNITIES USING RIVER TRAINING STRUCTURES

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 (Corps, 2000). St. Paul District's 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 not benefited from HREPs to date.

The remainder of Chapter 7 specifically discusses typical river training and side channel enhancement structure design/techniques in their own chapter subsection. The structures are:

1. Closure Structures
2. Wing Dam Notching
3. W-Weirs
4. Notched Closure Structures
5. L-Head Dikes
6. Spur Dikes
7. Alternating Dikes
8. Stepped Up Dikes
9. Bendway Weirs
10. Chevron Dikes & Blunt Nosed Chevrons
11. Off Bankline Revetment
12. Hard Points in Side-Channels
13. Vanes
14. Cross Vanes & Double Cross Vanes
15. J-Hook
16. Multiple Roundpoint Structures
17. Environmental Dredging
18. Longitudinal Peak Stone Toe
19. Bioengineering and Biotechnical Engineering
20. Wood Pile Structures
21. Root Wad Revetment
22. Woody Debris
23. Boulder Clusters
24. Fish Lunkers

1. Closure Structures. Closure structures are constructed across secondary channels to reduce floodplain conveyance and increase main channel depths. Rock (e.g., riprap) is used to partially or completely close secondary channels on the UMRS (photograph 7-1).

Photograph 7-1. Partial Closure Structure at the Weaver Bottoms Secondary Channel, Pool 5 (Jon Hendrickson, MVP 2005)

Secondary channel closure elevations should be constructed to the bankfull elevation or less. This increases the amount of floodplain conveyance occurring during flood events thereby restoring a more natural flow and sediment transport. If a secondary channel closure elevation is higher than the adjacent land (island or floodplain) high water events would increase erosive forces on the adjacent lands causing increased flood impacts.

There are two types of closure structures, the emerged closure structure and the submerged closure structure.

a. 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 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.

b. Emerged Closure Structures. There are six types of emerged structures:

i. 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. A low flow notch is often included in closure structures to allow continuous flow of water during low flow conditions and boat access.

ii. 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 toe scour causes some sloughing off the downstream side of the structure.
- A structure having 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.

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

iv. Construction Materials. There are three materials, rock, earth, and wood, used in closure structure construction.

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 vary depending on the site conditions and must be well coordinated with the geotechnical and hydraulic engineers.

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.

Wood. Trees and brush can be anchored to the bottom of a channel to cause sediment deposition to occur. This borrows on the technique 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 is not always the case in the northern pools of the UMRS.

v. 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 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.

vi. 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; and
- self adjusting rock is important to heal scouring should that develop.

vii. Case Studies

Lake Chautauqua. A submerged rock 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. This structure has a 15-foot wide by 3.5-foot boat notch. Photograph 7-2 shows the structure’s location between Liverpool Ditch and the Illinois River.

Photograph 7-2. Submerged Rock Closure Structure at Liverpool Ditch, Illinois River (August 2004)

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.

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.

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 tree shading 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-foot 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 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.

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 feet in case a scour hole developed downstream of the rock sill. If scour would start to under-mine 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 scour has not occurred at these rock sills. The rock sill top width probably could have been 10 feet 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.

2. Wing Dams Notching. Rock dams (also called dikes), running perpendicular to the shore, have long been used to guide the river and maintain the navigation channel. River engineers found simply by adding notches, the dikes continue to create navigation dimensions as well as support diverse habitats. Figures 7-1 and 7-2 show examples of notching.

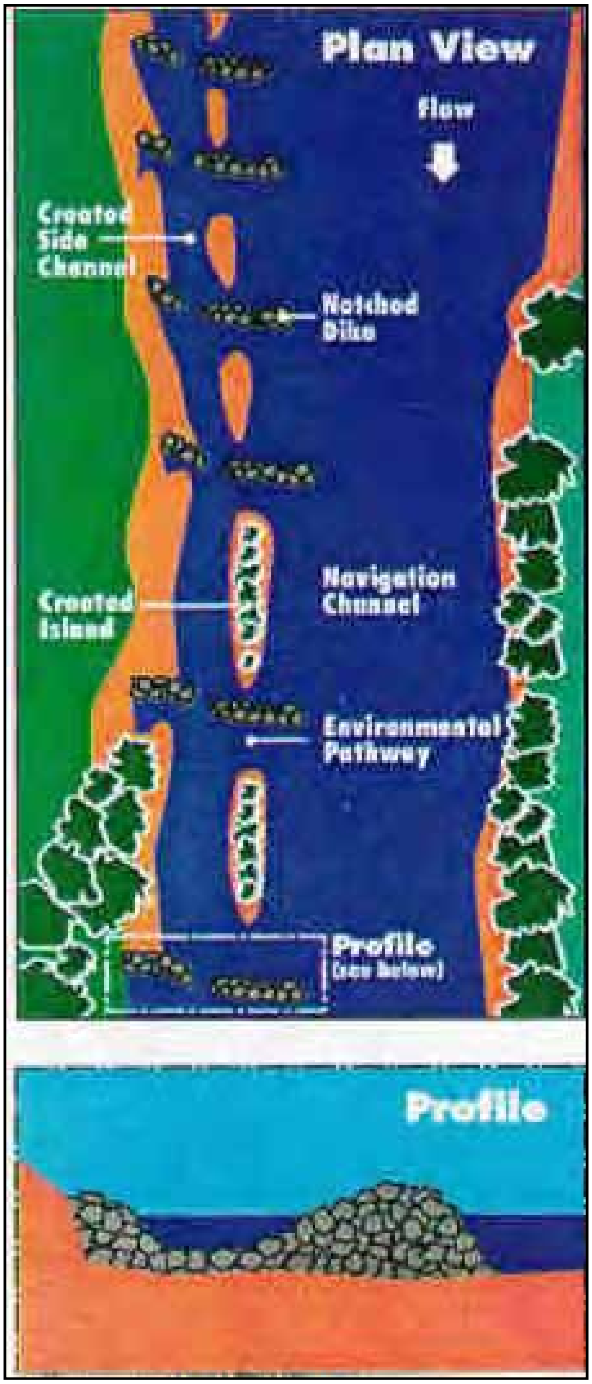


Figure 7-1. Wing Dam Notching

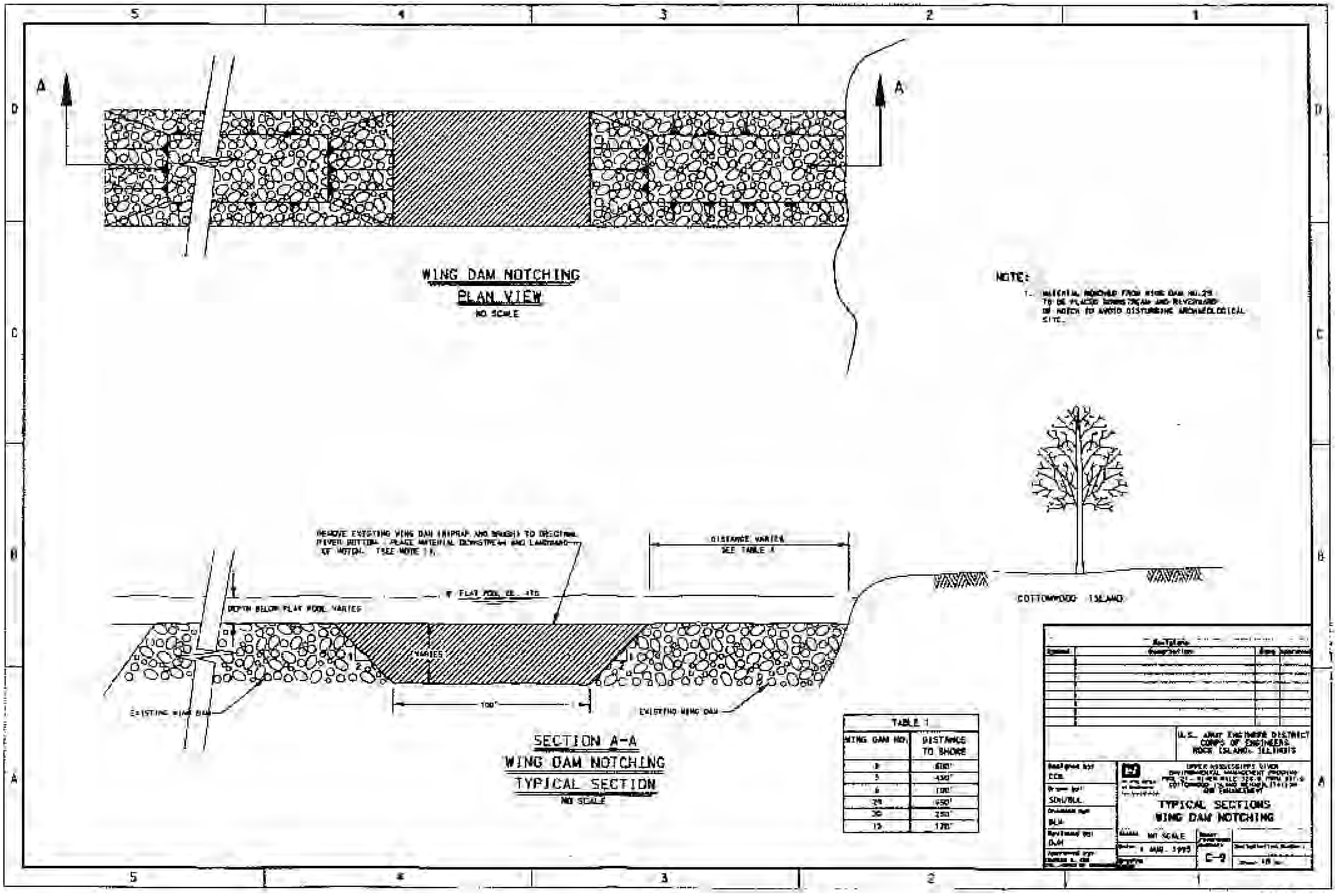


TABLE 1

WING DAM NO.	DISTANCE TO SHORE
8	600'
5	430'
6	100'
29	650'
30	250'
15	170'

Figure 7-2. Wing Dam Notching – Typical Section

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, 1980)

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. Burch et al. discussed notching emergent wing dams resulted in holes being eroded in the sediment downstream of the notch (1984). 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 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 locations characterized generally depositional in nature and the notches in the wing dams are not discernible, this may indicate 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 relatively unstable sandbars, 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 developing 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, (Hendrickson, 2005).

Burch et al., (1984) details a decision making process on notch location, and design. This technical manual is highly recommended resource.

a. Lessons Learned

- Rock size specification should be 400-lb. or larger rock, considering potential for interstitial spaces for critters or vary rock specification with expected hydraulic flow conditions versus sedimentation rates.
- Sizing/designing notches and other structures to naturally create plunge pools at higher flows providing 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 wing dams 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 (2205) in a laboratory.

b. Case Study

Cottonwood Island. Six wing dams were notched to provide flowing water habitat for fish and additional habitat and substrate for benthic and aquatic organisms. The notches were created by removing existing wing dam material to the original river bottom or a maximum of 10 feet below flat pool. Each notch was 100 feet long. Notches were staggered in anticipation that flow would increase in the vicinity of the notch, creating a scour hole behind the wing dams and stimulating a meander to the next wing dam (figure 7-3). Preliminary post-construction monitoring efforts indicate the formation of scour holes behind the wing dams and an increase in velocity at and below the notches (USACE, 2007)

Year 50 Target is to maintain velocities greater than or equal to 0.35, 0.5, and 0.4 feet per second at the following locations; 100 feet upstream of the notch, at the notch, and 100 feet downstream of the notch, respectively. Year 3 (2000) reported average velocities for Wing Dams No. 6 and No. 15 of 1.17 and 1.67 feet per second, respectively. Average velocity measurements at the notch and 100 feet downstream from the notch were considerably higher than those observed 100 feet upstream, which agrees with the results of similar studies reported by the Iowa Department of Natural Resources (USACE, 2007).

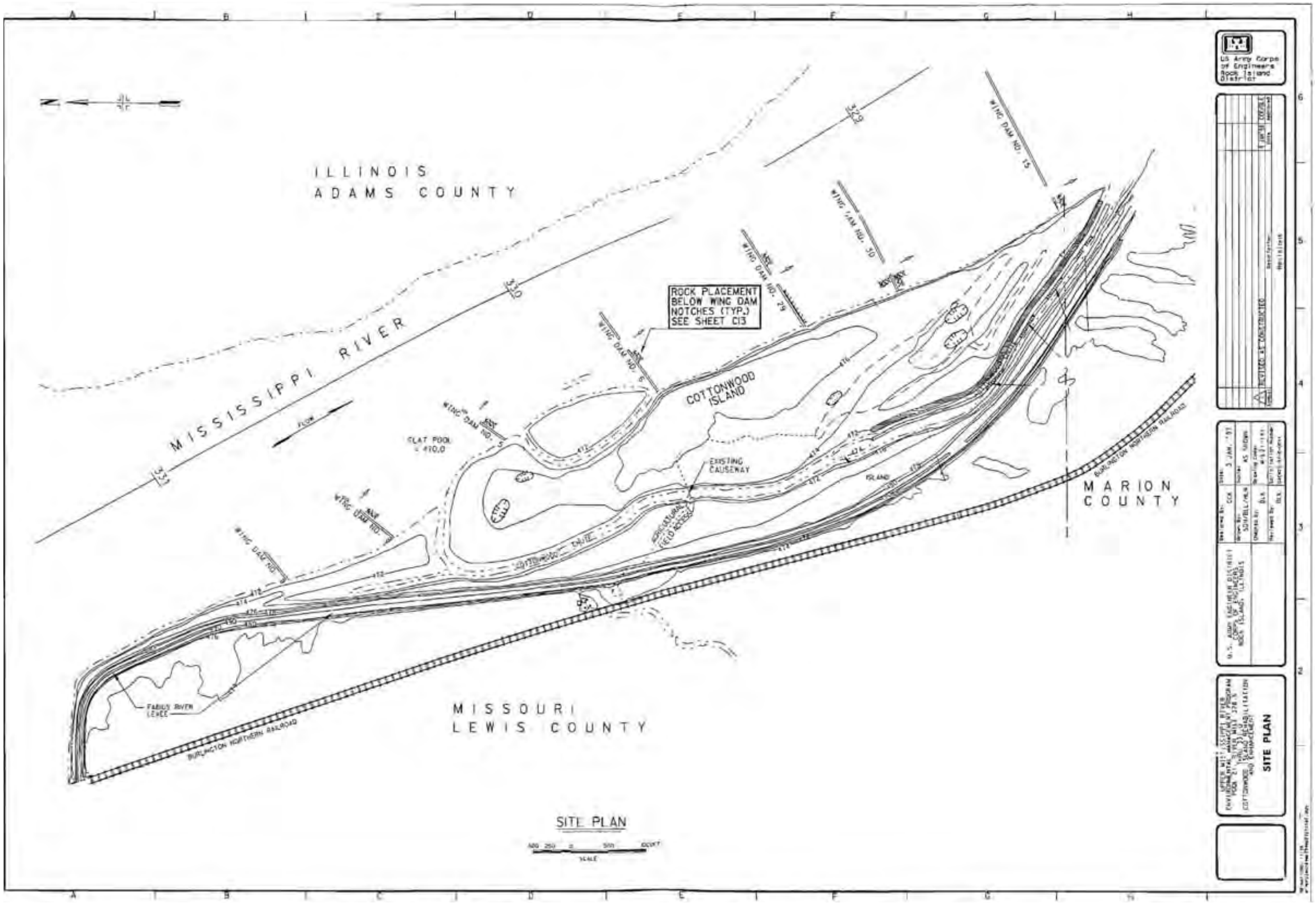


Figure 7-3. Cottonwood Island HREP; Wing Dam Notch Site Plan

3. W-Weirs. The design of the W-Weir (figure 7-4) was initially developed to resemble bedrock control channels on larger rivers. Various rock weirs installed across larger rivers for fish habitat, grade control and bank protection often create an unnatural and uniform "line of rocks" that detracts from visual values. The W-Weir is similar to a Cross-Vane in that both sides are vanes directed from the bankfull bank upstream toward the bed with similar departure angles. From the bed at ¼ and ¾ channel width, the crest of the weir rises in the downstream direction to the center of the bankfull channel creating two thalwegs. The objectives of the structure are to provide grade control on larger rivers, enhance fish habitat, provide recreational boating, stabilize stream banks, facilitate irrigation diversions, reduce bridge center pier and foundation scour, and increase sediment transport at bridge locations. Double W-Weirs are constructed on very wide rivers and/or where two center pier bridge designs (three cells) require protection (Rosgen, 1996).

a. Rock Size. Rock used for the construction of W-Weirs will meet the following size requirements, as shown in table 7-1. 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 should be 150 lbs/cu ft or greater.

Table 7-1. W-Weir Rock Size

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

b. Construction Methods

- W-Weirs are constructed with two 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 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 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 20^{o} -30^{o} 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 8 feet 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 percent to 7 percent 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.

- If applicable, stabilizing vegetation is seeded on top of the W-Weir.

- 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.

c. Lessons Learned . None listed.

d. Case Studies. None listed.

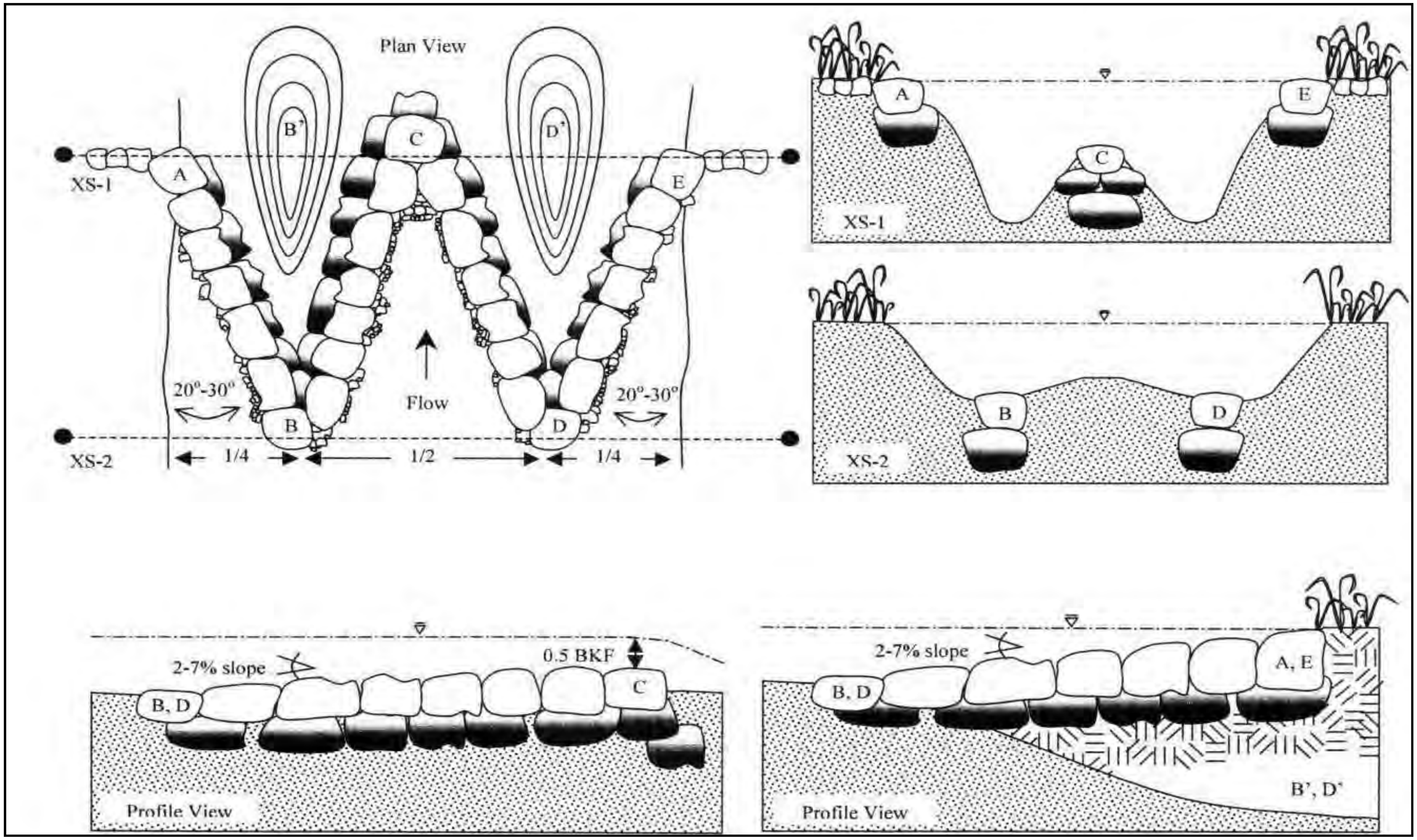


Figure 7-4. Plan, Cross Section, and Profile Views of the W-Weir (Rosgen, 2001)

4. Notched Closure Structures. 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 7-5).

a. Lessons Learned: Notches should be able to accommodate pleasure boat traffic. The notch’s bottom elevation should be at least 3.5 feet below flat pool elevation.

All closing dams should have bankline protection on both shorelines. Many closing dams create eddies on the downstream side of the structure and will scour the adjacent river banks.

b. Case Studies None listed.

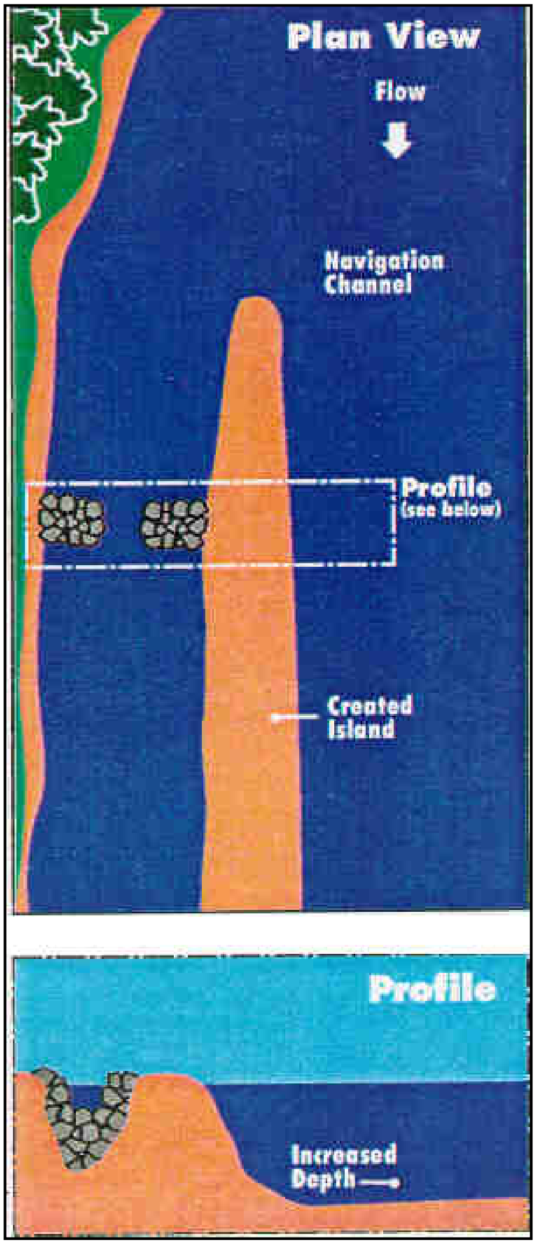


Figure 7-5. Notched Closure Structures

5. L-Head Dikes. 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 7-3 shows an example.

Photograph 7-3. L-Head Dike, Marquette Chute, near Middle Mississippi River Mile 51.0L

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.

a. 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.

b. Case Studies

Kansas River at Eudora Bend, KS

Monkey Run at Arcade, NY

Eighteen Mile Creek Salmon Stream Restoration, Newfane, NY

6. Spur Dikes. Spur Dikes 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 bed loads 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. Figure 7-6 shows an example of spur dikes.

Spur dike performance is enhanced when there are several dikes in a series. Spur dike performance also relies on placing the crest of each dike 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.

Franco (1967) evaluated dike performance and developed some parameters considered in general dike construction. These parameters should be considered in the spur dike planning stage.

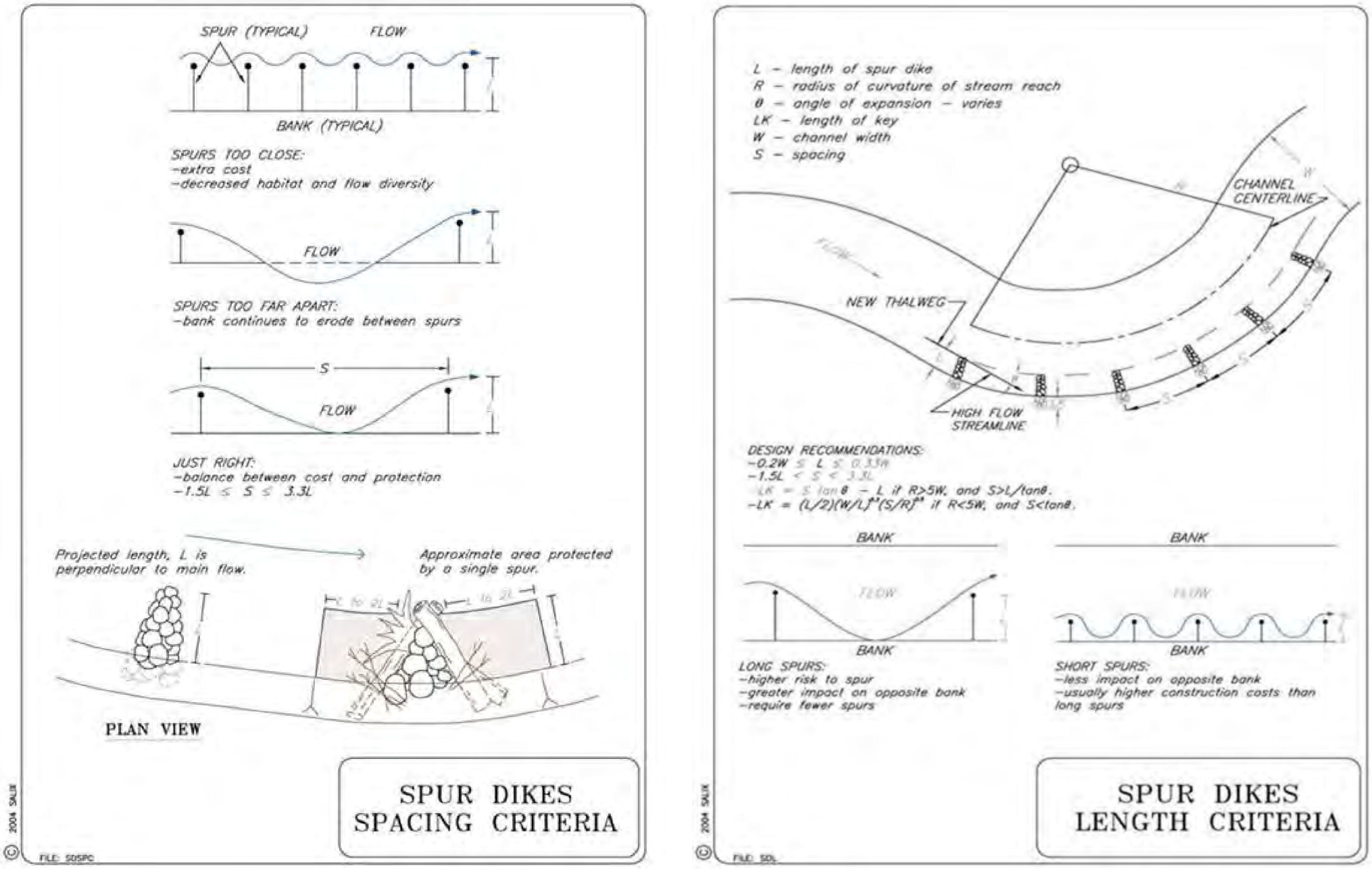


Figure 7-6. Spur Dikes (Source: www.e-senss.com)

a. 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.

7. Alternating Dikes. 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 previously having 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 7-4 and 7-5 show examples of alternating dikes.

The altered flow patterns typically put additional flow along the bankline, opposite each dike which induces erosional tendencies. Therefore, these privately owned areas, there is a presence of infrastructure, or if lateral movement of the bankline is simply not desired, the bankline should be armored with stone. 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 hydraulic sediment response model but keep in mind this is just one model. Model types should be dictated by data and needs of the project. 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.

Photograph 7-4. Alternating Dikes

Photograph 7-5. Alternating Dikes

a. Lessons Learned. Most dikes built along the main channel border are typically ½ to 2/3 bankfull height. This elevation is 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.

b. Case Study

Santa Fe Cute. The St. Louis District micro modeled Sante Fe Chute in 1996 to study various methods of rehabilitation. This project is shown in photograph 7-6. 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.

Photograph 7-6. Santa Fe Chute Alternating Dikes

After monitoring the riverbed, it was determined 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.

8. Stepped Up Dikes. Stepped-up dike fields of various elevations provide an additional element of riverine habitat 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 upstream dike. This approach utilizes the river's energy to change the sediment deposits as the water level rises and falls (figure 7-7).

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.

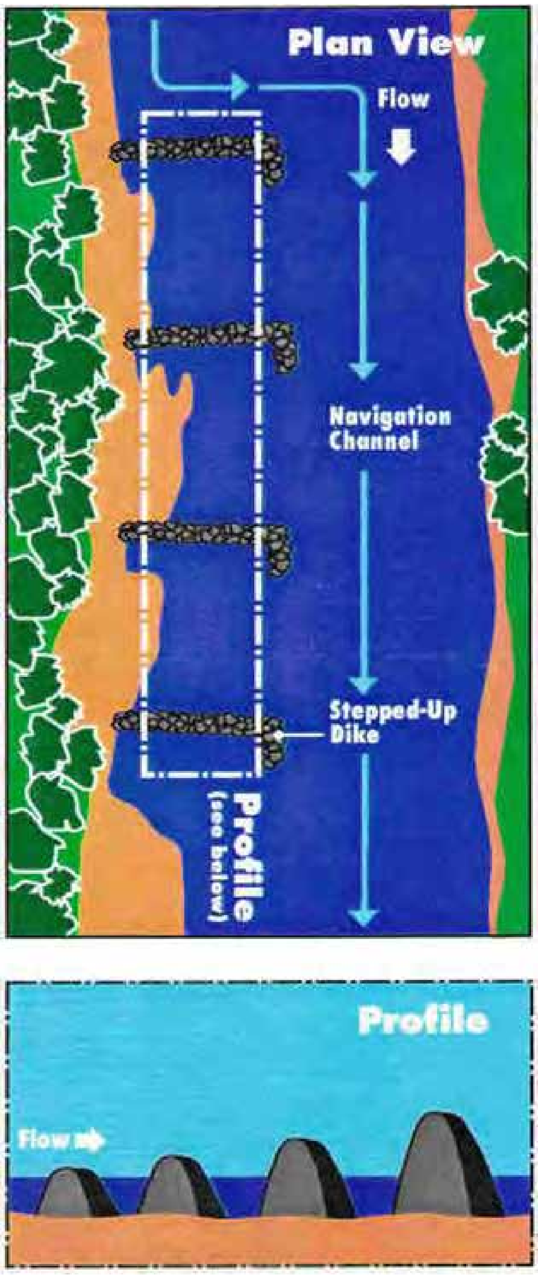


Figure 7-7. Stepped Up Dikes

a. Lessons Learned. None listed.

9. Bendway Weirs. The bendway weir is a low level, totally submerged rock structure positioned from the outside bankline of the river bend 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 (Davenroy, 1990).

The bendway weirs have not only provided navigation benefits, but many significant environmental benefits as well. A wider and more smoothly aligned navigation channel has resulted so 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 use the weir fields for their habitat. Figure 7-8 shows bendway weirs.

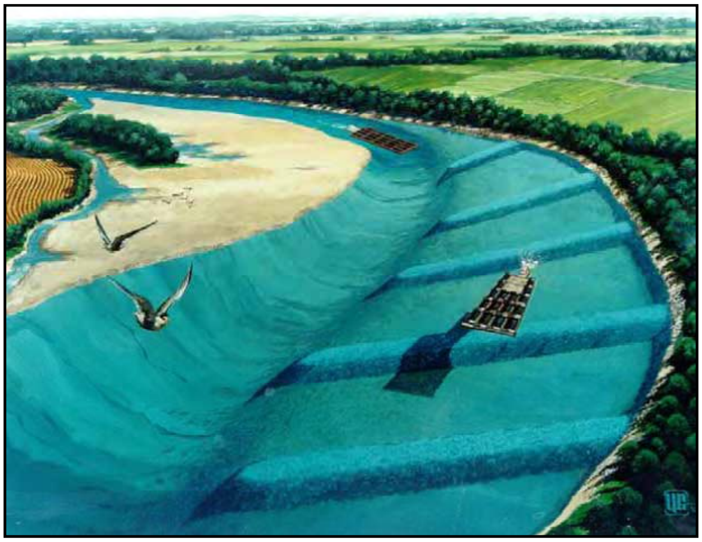


Figure 7-8. Bendway Weirs

The Missouri Department of Conservation tested the diversity in habitats surrounding a test section of bendway weir. Their raw data showed a total of 4,512 fish and 45 different species used the test site's bendway weir. 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. Figures 7-9 and 7-10 show the functions of a bendway weir.

a. 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.

b. Case Study

Bendway Weirs. Nearly 200 weirs have been placed in the Mississippi River since 1990. The St. Louis District has a website (http://www.mvs.usace.army.mil/arec/reports_bendwayweirs.html) that provides a very comprehensive and detailed presentation of the development and application of bendway weirs. This reference provides an excellent source of design information for river engineers in the use of bendway weirs in a navigation channel.

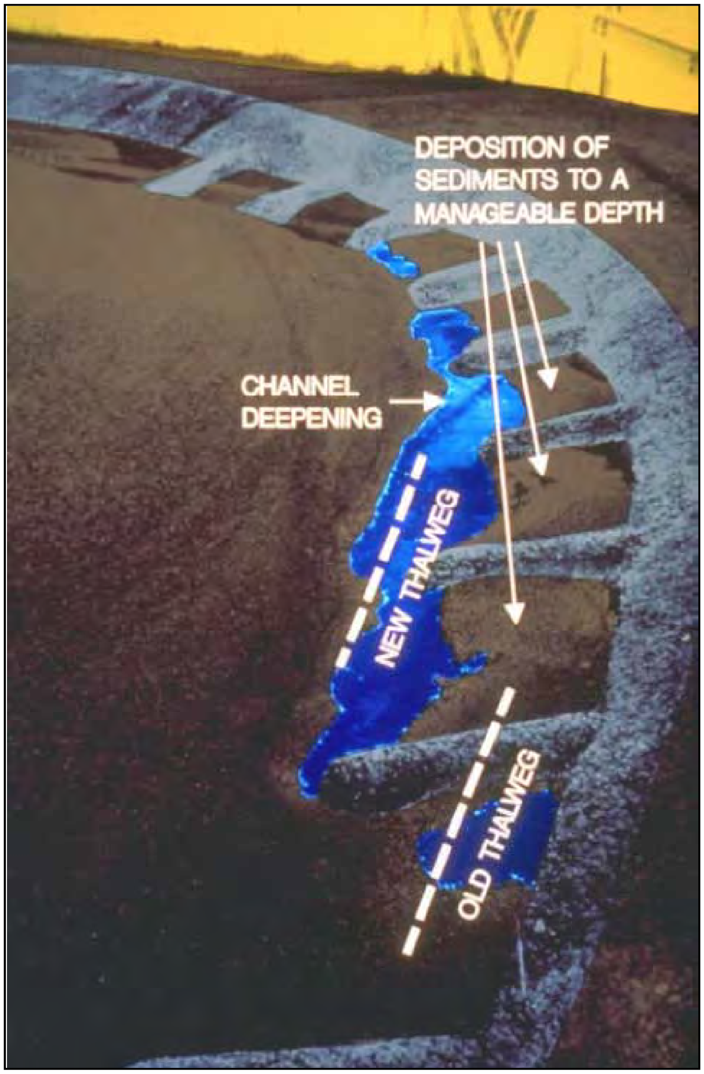


Figure 7-9 Bendway Weirs: Functions

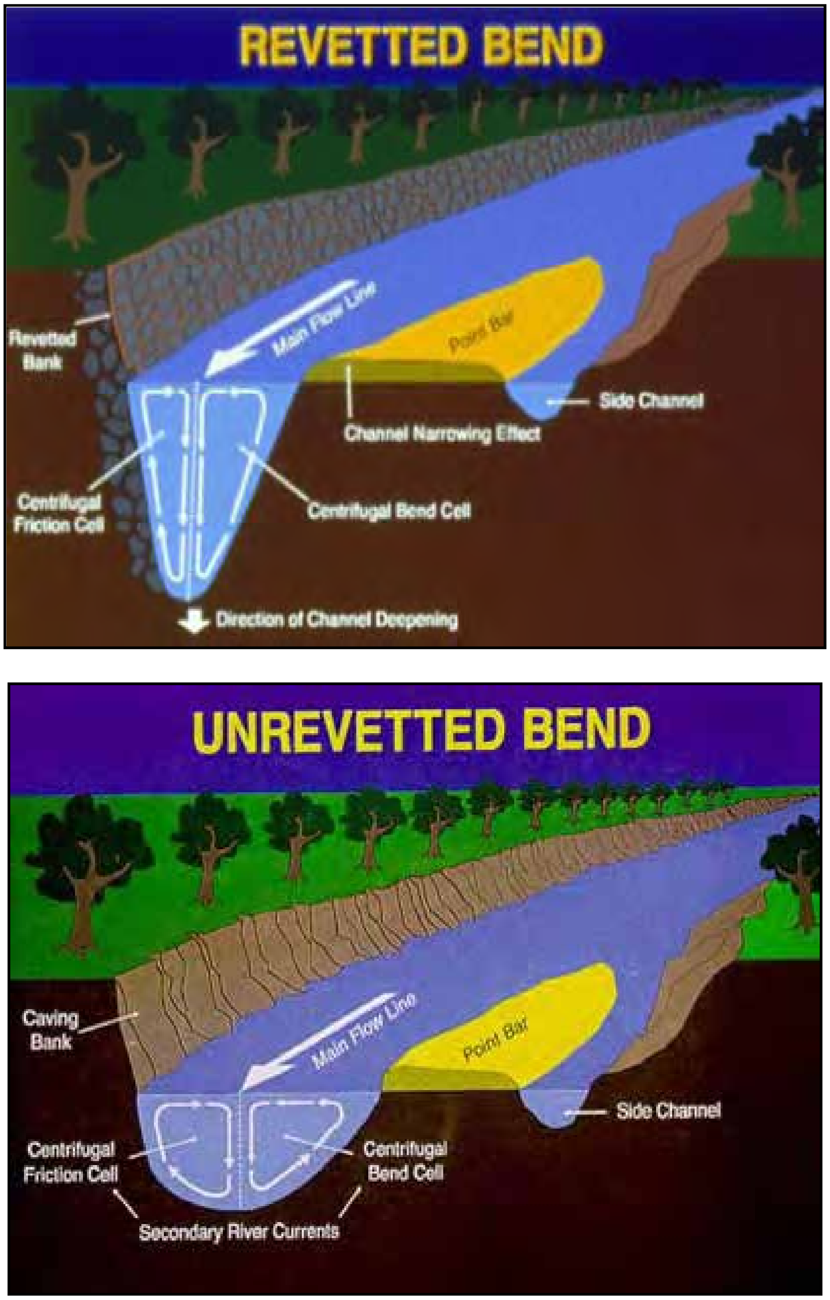


Figure 7-10. Bendway Weirs: Revetted and Unrevetted Bends

10. Chevron Dikes and Blunt Nosed Chevrons. Chevrons usually are not attached to the shoreline like the typical wingdam. All chevrons are V- or U-shaped rock structures pointing upstream. Not only do chevrons divert river flow like a wingdam, toward the main channel, they also create several different types of river habitat, with variable depth and flow velocities.

All types of chevrons are typically built above normal flat pool elevation to a 2-year flood elevation. River flows overtopping the structures during high water periods create a large scour hole inside of the chevron just downstream of the structure's apex. Downstream of this area the reshaped material deposits create a shallow bar.

The rock dike substrate may provide habitat for epilithic (rock dwelling or attached to rock) macroinvertebrates capable of colonizing in very high densities and providing an important food source for fish. Chevrons create habitat heterogeneity and appear to increase invertebrate abundance and diversity (Ecological Specialists, Inc. 1997) and provide useful and valuable habitat for a large variety of riverine fishes (Atwood 1997). Although this study investigated revetments, similar rock and hydraulic configurations at chevrons should create similar biological responses.

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 juvenile and larval fish nursery. The potential plant life established along the wetted edges and uneven rock structure would provide good escape cover and foraging habitat for young fish.

The scoured material usually forms an island or builds on an existing island (in the case of a blunt nose chevron) immediately downstream of the structure. The islands encourage the development of variety of river habitats.

There are two types of chevrons - chevron dikes and blunt nose chevrons. Chevron dikes generally are used for navigation purposes whereby water is diverted towards the navigation channel for channel maintenance purposes. Blunt nose chevrons are used to protect the head end of islands from erosion.

a. Chevron Dikes. A chevron dike is a navigation structure that reduces dredging and improves river habitat. These structures are placed in the shallow side of the river channel pointing upstream. They are designed to push water towards the navigation channel. Sometimes when dredging is needed to improve the main navigation channel, dredged sediment can be deposited behind the chevron dike forming an island. These islands are important in the lower portions of pools where most of the historic island have been lost due to deepening the pools and erosion.

Chevrons are typically used in wider reaches of the river where a flow split is desired (photographs 7-7 and 7-8). 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 7-7. A Series of Chevron Dikes on the Mississippi River

Photograph 7-8. A Series of Chevrons Aligned To Split Flow Between the Main Channel and a Side Channel, While Protecting the Existing Shoreline

b. Bluntnose Chevrons. Bluntnose, or bull nose, chevrons are designed to protect the nose of the island and the sharply vertical bankline (figure 7-11). Typical chevron design dimensions are discussed in the Gardner Division Case Study, page 7-32, provides typical chevron design dimensions). 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 to 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 7-9.

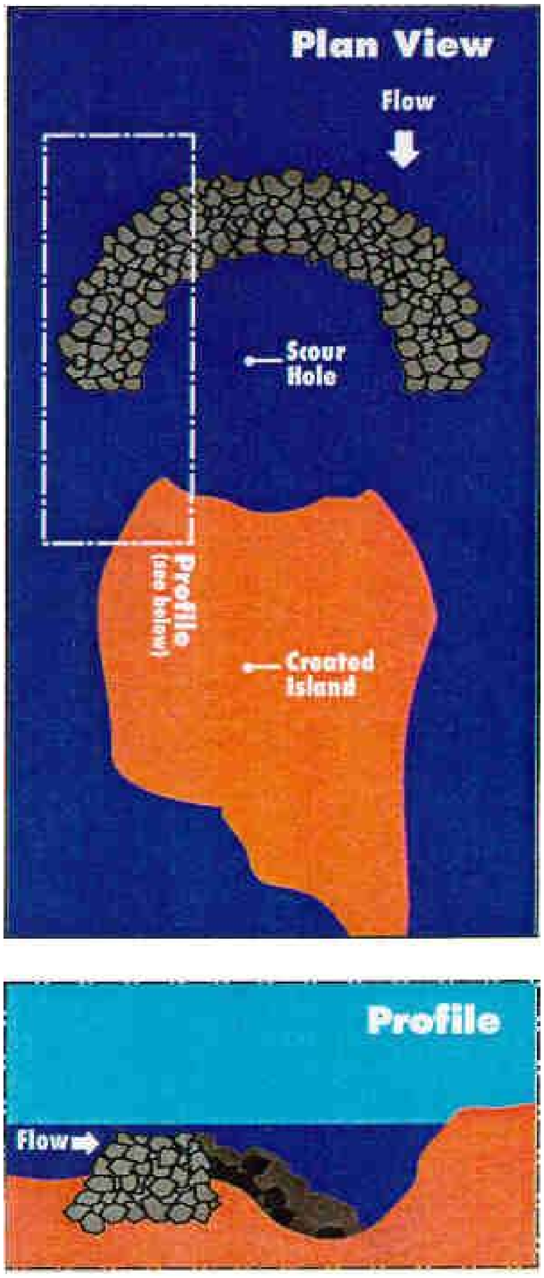


Figure 7-11. A Blunt Nosed Chevron Above an Island

Photograph 7-9. Cottonwood Island Chevrons

c. Lessons Learned. The first three experimental chevrons were constructed in Pool 24 near RM 290 in 1993 solely for the purpose of protecting dredged material. Initial monitoring of the chevrons showed they had immense environmental benefits by creating an abundance and variety of aquatic habitat (Ecological Specialists, Inc. 1997). Since then, these chevrons as well as three additional chevrons near URM 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 suggest the structures are being used as nursery habitat. The data also shows 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 using the islands have 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.

Training structure work is commonly completed using large deck mounted cranes and rock barges. This work is usually completed in areas normally shallower than the main 9-foot channel which may make mobilization and demobilization a challenge. Construction should be scheduled at water levels conducive to mobilization to the project site.

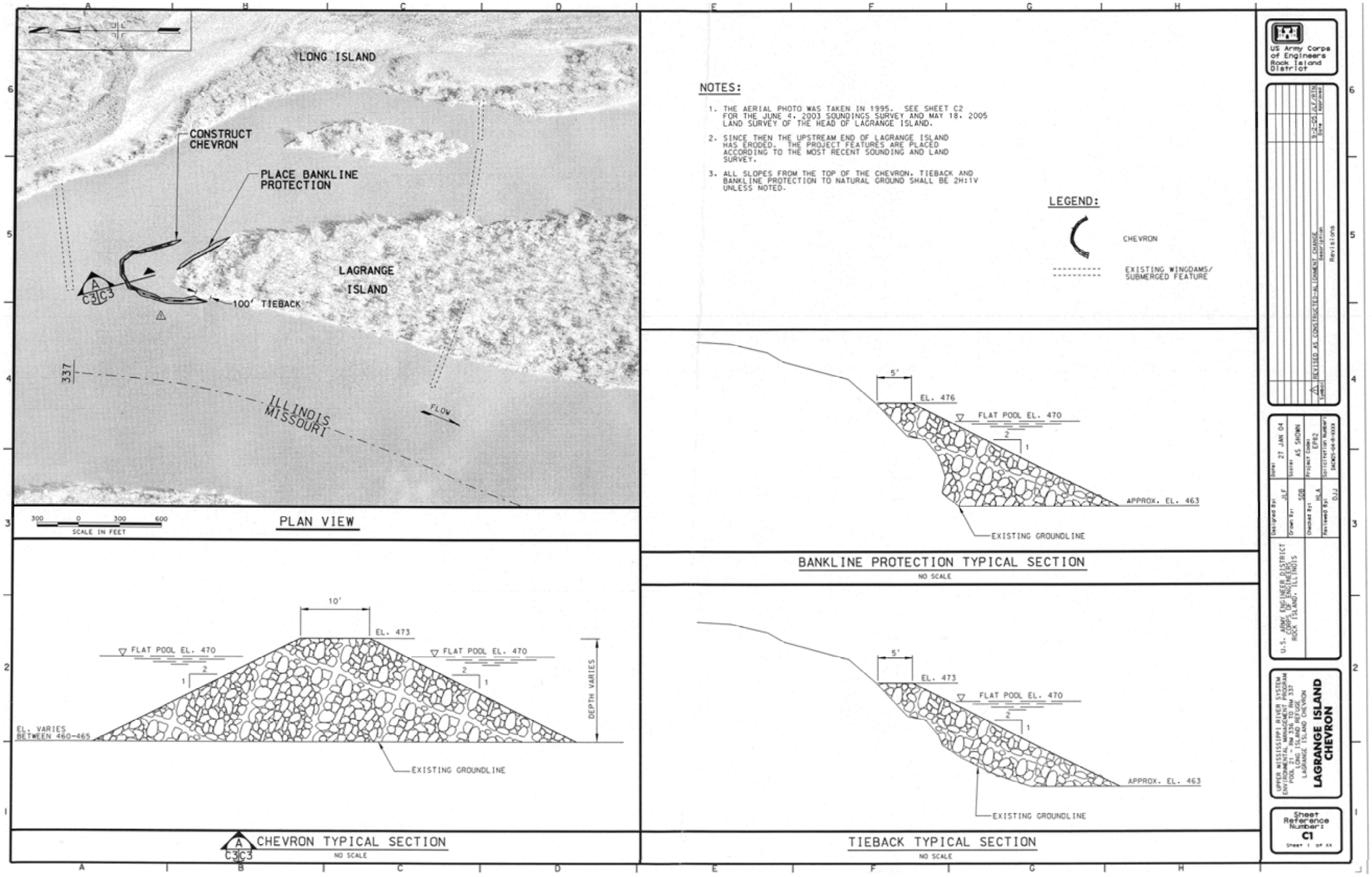
d. Case Studies - Chevrons

St. Louis Harbor. Chevrons work better when used in a series. Bank revetment is typically needed on the near back of the structures. They are typically built at +2 feet above normal pool.

Gardner Division (LaGrange Island, Pool 21, constructed 2005). The initial layout of this bluntnose chevron was created by following previously deposited rock located on or near the head of LaGrange Island as part of the 6-foot navigation project (photographs 7-10 and 7-11 and figure 7-12). The height of the chevron was determined by viewing previously-built chevrons from the St. Louis District and reviewing the height of nearby closing dam and wing dam structures. The bankline next to the tieback eroded away and the head of LaGrange was still eroding. Improvements include increasing the tieback area to at least 300 linear feet and increasing the height of the chevron (figure 7-13).

Photograph 7-10. LaGrange Island Bluntnose Chevron in 2011

Photograph 7-11. LaGrange Island Bluntnose Chevron Rock Placement, Looking South East – August 2005



NOTES:

1. THE AERIAL PHOTO WAS TAKEN IN 1995. SEE SHEET C2 FOR THE JUNE 4, 2003 SOUNDINGS SURVEY AND MAY 18, 2005 LAND SURVEY OF THE HEAD OF LAGRANGE ISLAND.
2. SINCE THEN THE UPSTREAM END OF LAGRANGE ISLAND HAS ERODED. THE PROJECT FEATURES ARE PLACED ACCORDING TO THE MOST RECENT SOUNDING AND LAND SURVEY.
3. ALL SLOPES FROM THE TOP OF THE CHEVRON, TIEBACK AND BANKLINE PROTECTION TO NATURAL GROUND SHALL BE 2H:1V UNLESS NOTED.

Figure 7-12. LaGrange Island Blunt Nose Chevron Design – Typical Sections

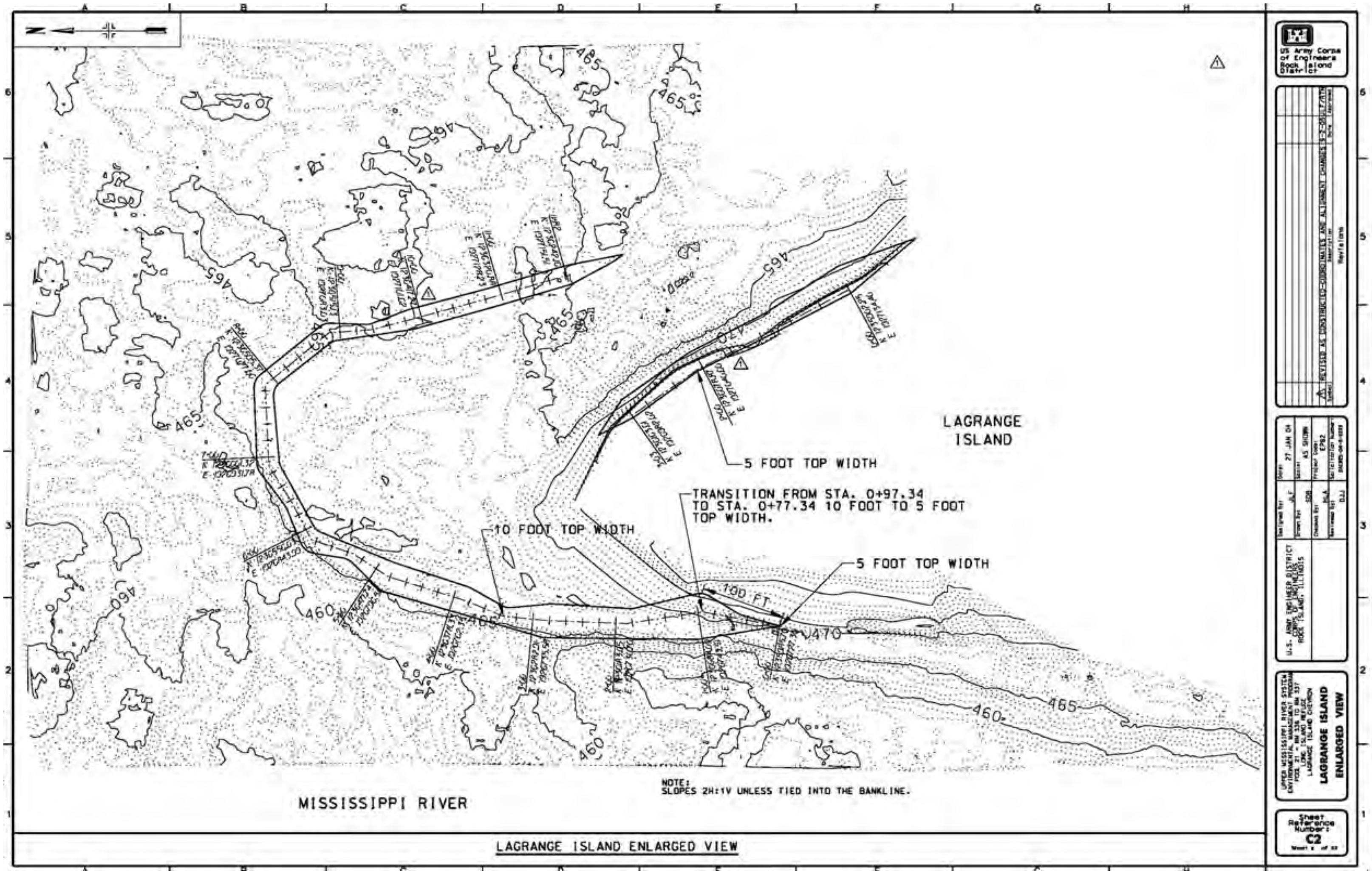


Figure 7-13. LaGrange Island Blunt Nose Chevron Design - Overview

11. Off-Bankline Revetment. 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 7-14).

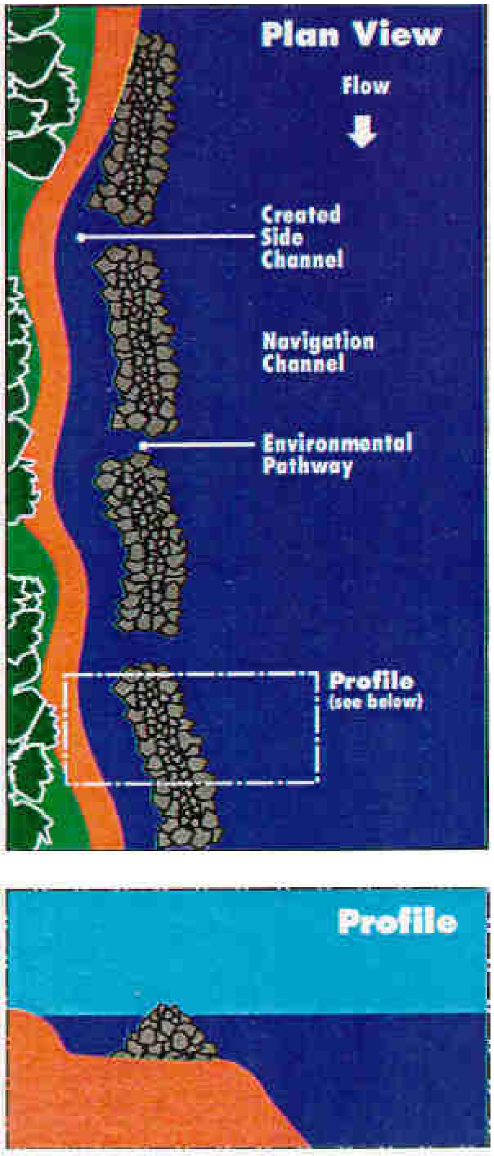


Figure 7-14. Off-Bankline Revetment

a. Lessons Learned. None listed.

b. Case Study

Wing Dam Improvements at Hershey Chute, RM 461.5 (constructed mid 1990s)**.** The Rock Island District has a chronic dredge cut between RM 461.0 and 463.8 in Pool 16 of the Mississippi River. The District constructed rock revetments adjacent to a narrow piece of land separating the main river channel and the Andalusia Island HREP project. This project restored a backwater marsh important to migrating waterfowl. The revetments served three purposes. Initially the protected area was used by fish for a spawning area. Eventually the District used it as a dredge material placement site. The rock revetment also protected the narrow piece of land, from erosion, thereby protecting the habitat behind the island (photographs7-12 and 7-13).

Photograph 7- 12. Hershey Chute Rock Revetment, River Mile 461.5, circa 2000

Photograph 7- 13. Hershey Chute Rock Revetment, River Mile 461.5, circa 2012

12. Hard Points in Side Channels. Hard points (figure 7-15) 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 7-15. Hard Points

a. 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. Hard points are a good choice for straight reaches and large radius bends; and 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.

b. Case Study

Duck Island Side Channel. 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 7-14 and 7-15).

Photograph 7-13. Duck Island Hard Points

Photograph 7-14. Owl Creek Hard Points

13. Vanes. Rock vanes are in-stream structures constructed for the purpose of reducing shear stress on streambanks. Rock vanes 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 should be of hard enough to resist weathering and free of cracks and other blemishes. Porous rock such as some limestones, soft rock such as shale, concrete, or other “debris” should not be used for vanes. Figure 7-16 shows typical vane details.

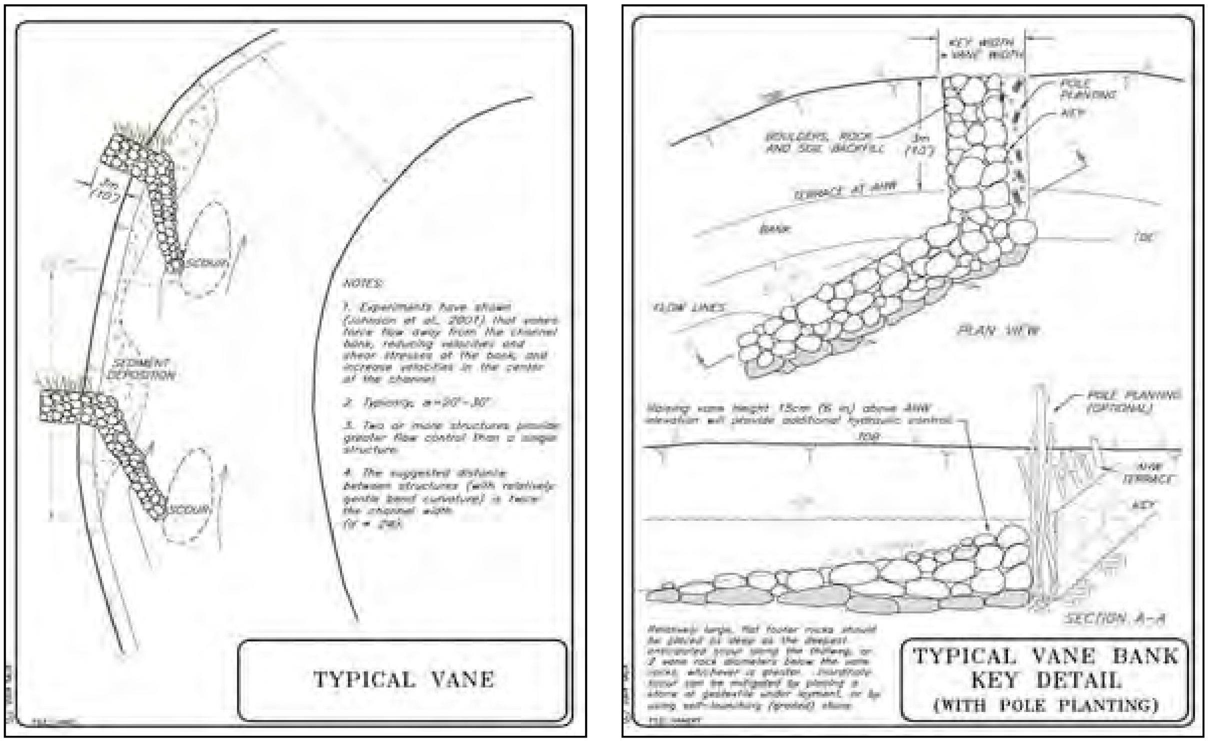


Figure 7-16. Typical Vane Details

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 7-17 and 7-18 show flow around an Iowa vane.

Iowa 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.

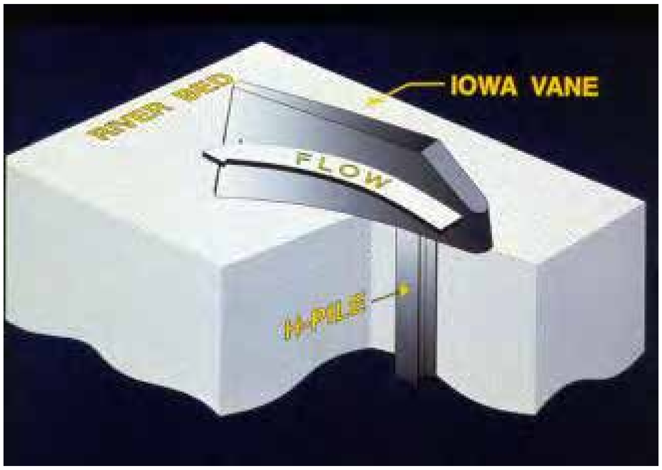


Figure 7-17. Iowa Vane

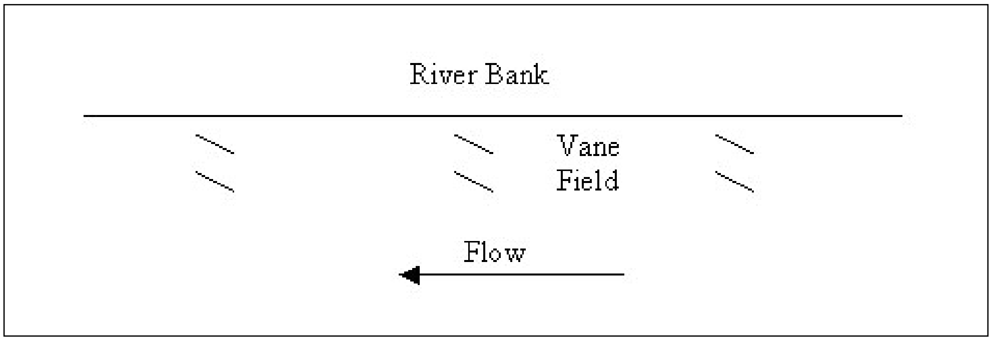


Figure 7-18. Flow Field

Russian engineers Potapov and Pyshkin (Rosgen, 1996) originally proposed the use of vanes or panels for flow training. However, it is only recently 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 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 7-2).

Table 7-2. 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

a. 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.

b. Case Studies

West Fork Cedar River, IA. Photograph 7-15 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 7-15. Aerial Photograph 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 7-16 shows 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 7-16. Vane System - Kosi River, Nepal

14. Cross Vane and Double Cross Vane. 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 fish, and; (6) create grade control to prevent down cutting.

Rock should be hard enough to resist weathering and 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 7-19.

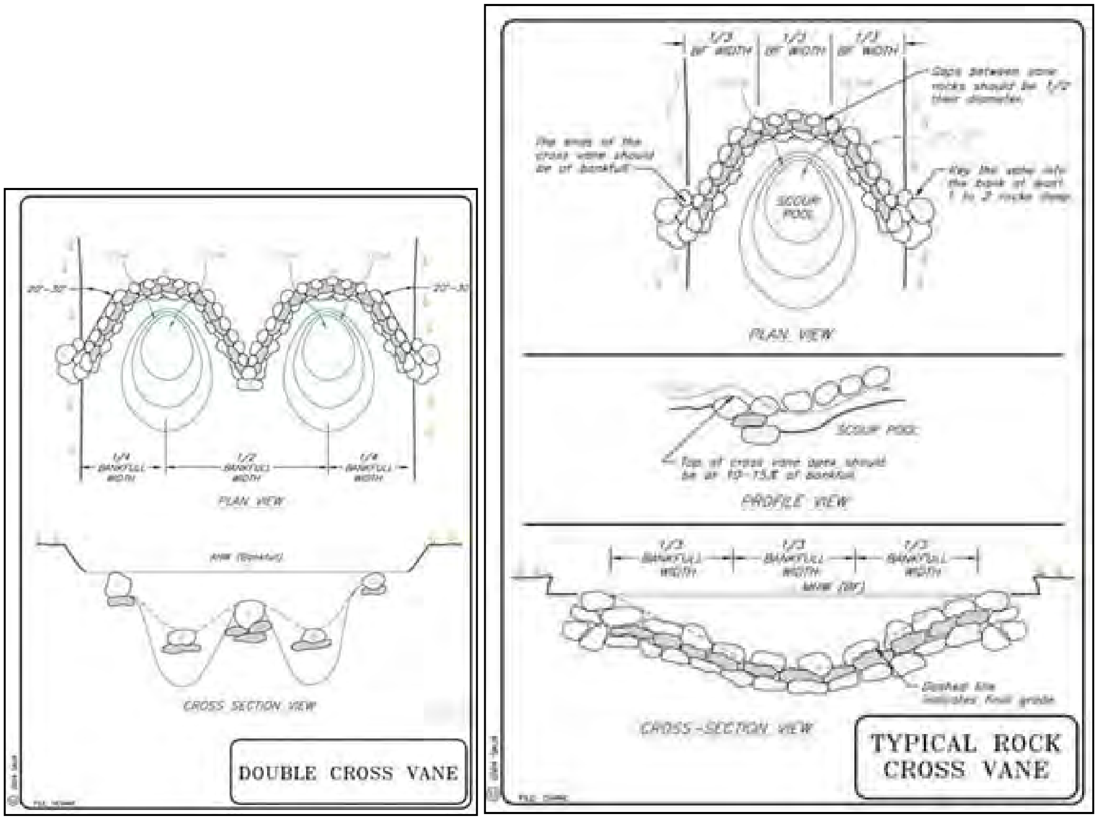


Figure 7-19. Typical Cross Vane Details

a. Lessons Learned. When the rock is placed, make sure 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.

b. Case Studies. None listed.

15. J-Hook. J-Hook Rock Vanes (figure 7-20) are structures designed to re-direct velocity distribution and high velocity gradient in the near-bank region, stabilize streambanks, 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 water will flow over immoveable objects at right angles (90° angles). The device is constructed of large stone tied into the stream bank. 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 the top of the rock is approximately level with the stream bottom.

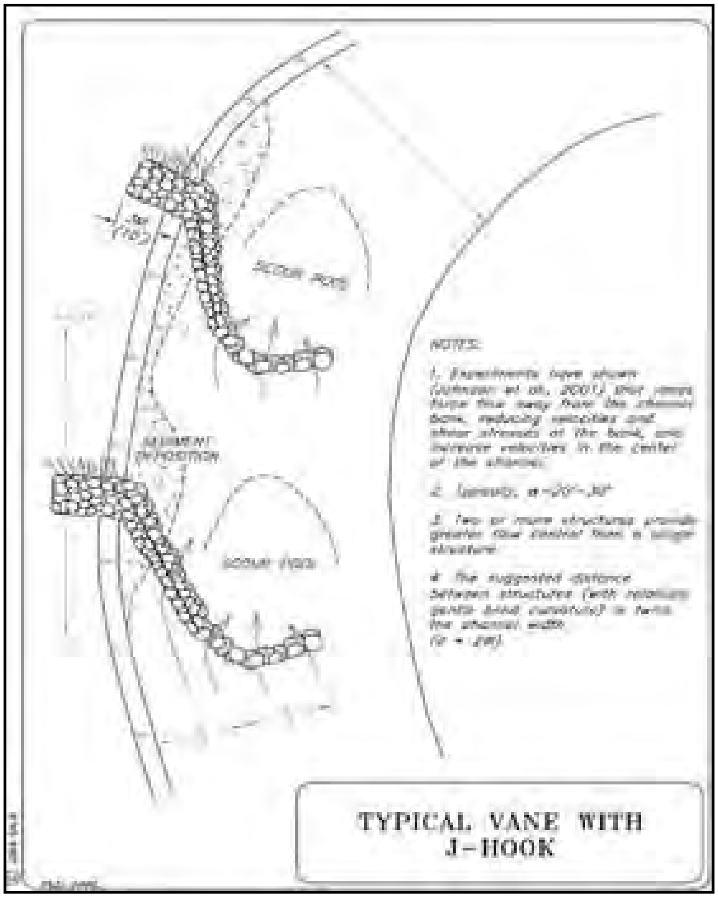


Figure 7-20. Vane With J-Hook

The second row of rock is then placed just upstream of that row of rock slightly overlapping it so the water flows over the top of the upstream line of rock slightly overlapping it. 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 serving as a source of aquatic habitat.

a. Lessons Learned. When the rock is placed, make sure 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 (McCullah, 2004).

b. Case Study

Marion Creek, AK used J-Hook Structure (photograph 7-17)

Photograph 7-17. Marion Creek, AK

16. Multiple Roundpoint Structures. Multiple Roundpoint Structures (MRS) (figure 7-21) are used to create bathymetric and flow diversity in streams and rivers. The MRS induce scouring off 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 downstream of the structures. The MRS can also act as a primitive bank stabilization technique by creating depositional zones near the banks of the structures (USACE, 2000).

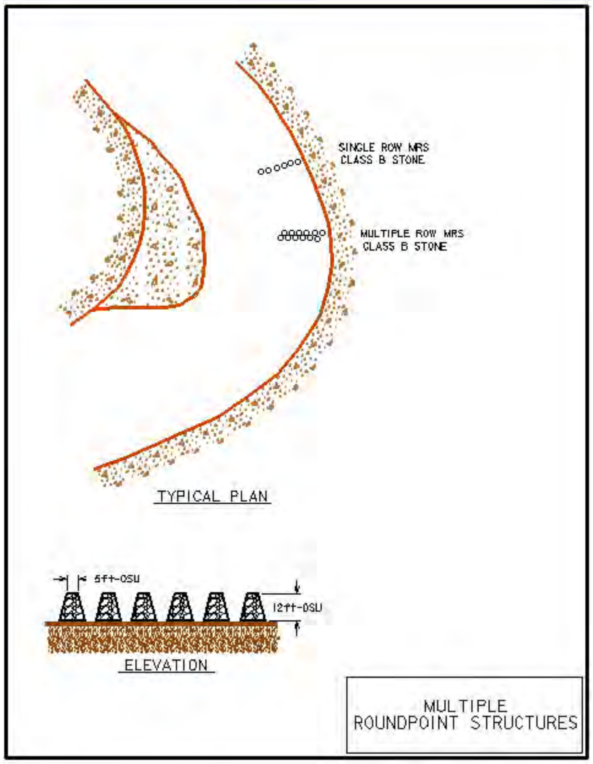


Figure 7-21. Multiple Roundpoint Structures

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 the more rows incorporated generate increased bathymetric changes.

a. 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 Longitudinal Peak Stone Toe. The data collected suggest 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.

b. Case Studies. Photograph 7-18 shows an MRS on the Mississippi River.

Photograph 7-18. US Army Corps of Engineers, St. Louis District Riprap Landing Multiple Roundpoint Structures, Middle Mississippi River Mile 265.7.

17. Environmental Dredging. 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 (USACE, 1995). 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 7-19).

Photograph 7-19. Dredge Using Hydraulic Pipeline

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 3,000 feet away.

a. Lessons Learned. Dredging is coordinated with other government agencies so the Corps 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 associated with channel dredging.

b. Case Study

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

18. Longitudinal Peak Stone Toe Protection (LPSTP). 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 consideration for LPSTP keys indicates 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 7-22 and photograph 7-20).

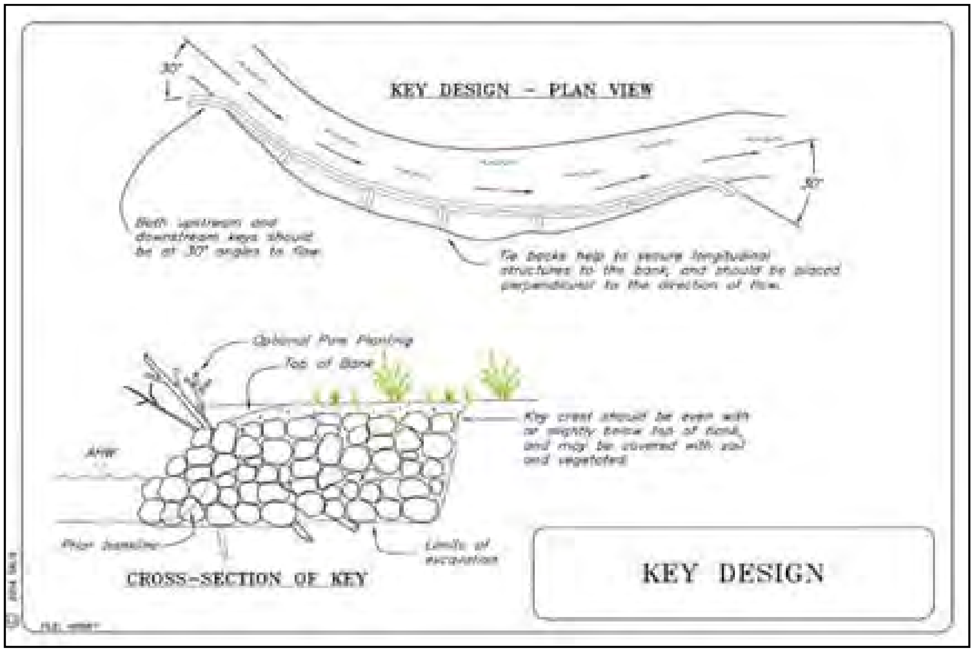


Figure 7-22. Longitudinal Peak Stone Toe Protection

Photograph 7-20. Longitudinal Peak Stone Toe Protection

a. 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).

b. Case Studies. None listed.

19. 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 describing 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 combining 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 7-21 shows an example of bioengineering.

Photograph 7-21. Rock Vanes with Bioengineering, Urban Setting, Charlotte, NC (photograph: Andrew Burg)

Following are specific ways vegetation can protect stream banks as part of a biotechnical engineering approach.

- 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.

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; and
- requiring significant maintenance.

More importantly, the type of plants surviving 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 7-22.

Photograph 7-22. Bioengineering Using Willow

a. Design Considerations for Biotechnical Engineering. In an unstable watershed, careful study should be made of the causes of instability before biotechnical engineering is contemplated (FHA, 2001, 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 (FHA, 2001) consequently, most biotechnical engineering projects documented in the literature contain some form of structural (hard) toe stabilization, such as rock riprap (figure 7-23), rock gabions, cribs, cable anchored logs, or logs with root wads anchored by boulders (figure 7-24).

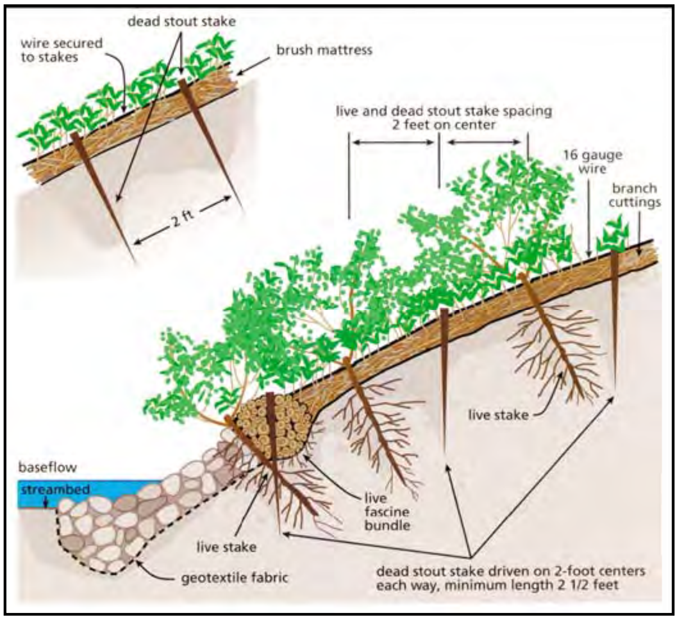


Figure 7-23. Details of Brush Mattress Technique With Stone Toe Protection

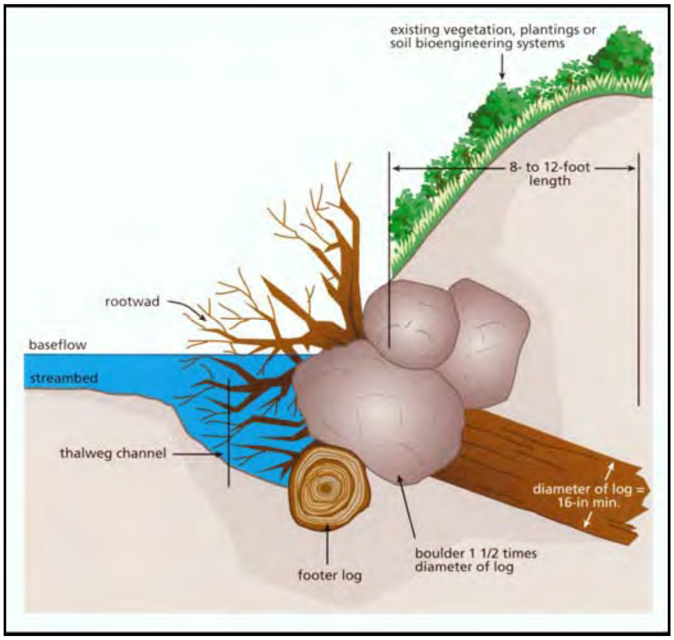


Figure 7-24. Details of Root Wad and Boulder Revetment Technique

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.

b. 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 (1998). 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 7-25).

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.

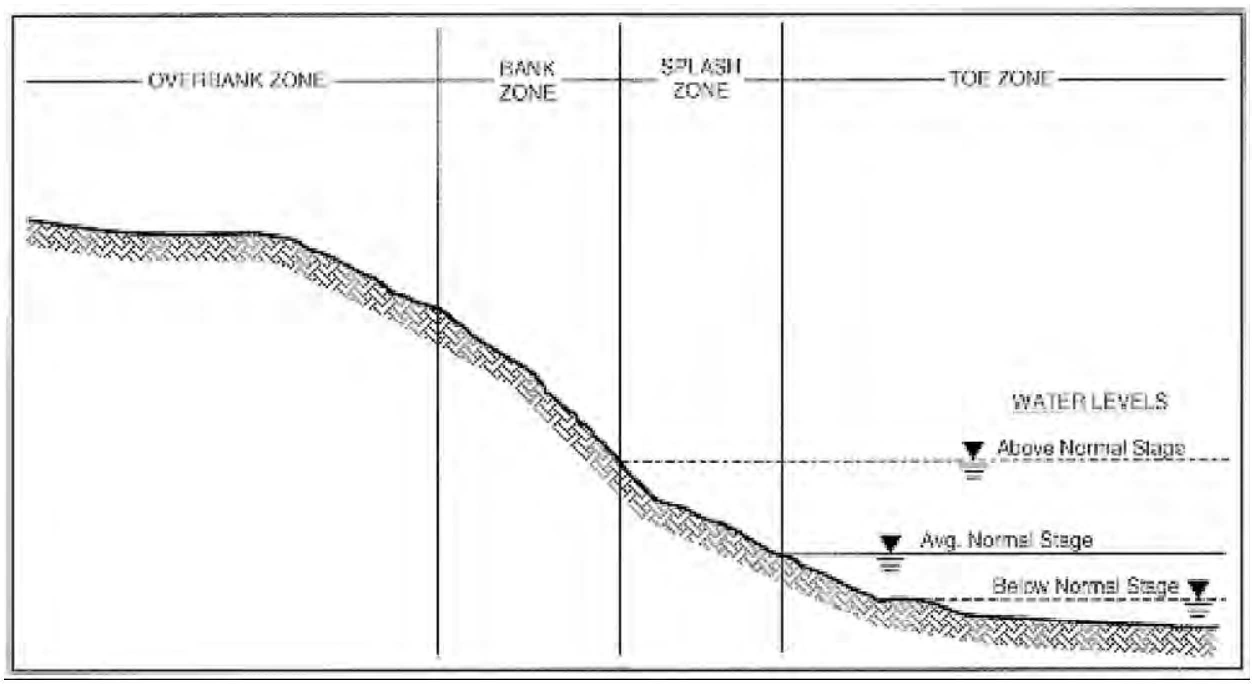


Figure 7-25. Bank Zones Defined for Slope Protection

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 (1979) 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.

c. Biotechnical Engineering Treatments. Descriptions and guidelines for biotechnical engineering treatments or combinations of treatments, and plant species used in the treatments are described in detail by WES,(1998) Bentrup and Hoag,(1998) and Schiechtl and Stern (1997). 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.

i. 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.

ii. 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.

Willows can be harvested at project construction inception so material can be soaked for as long as possible to increase chances of survival during summertime planting Research shows 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, consist 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 7-20).

Root pads are clumps of shrubbery composed of woody species that are often placed in the splash zone between root wads (figure 7-22). Root pads can also be used in the bank and overbank zones, but should be secured with stakes on slopes greater than 1V:6H.

iii. 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 is 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.

iv. 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 is 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.

d. Summary . Biotechnical engineering is 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.

e. 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.

f. Case Studies. None Listed

20. Wood Pile Structures. 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. 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 their benefit to the micro and macroinvertebrate species.

a. **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.

b. **Case Study**

Apalachicola River, FL. Photograph 7-23 shows a permeable wooden pile dike on the Apalachicola River, FL

Photograph 7-23. Permeable Wooden Pile Dike on the Apalachicola River, FL

21. Root wad Revetment. 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 7-26 and photograph 7-24).

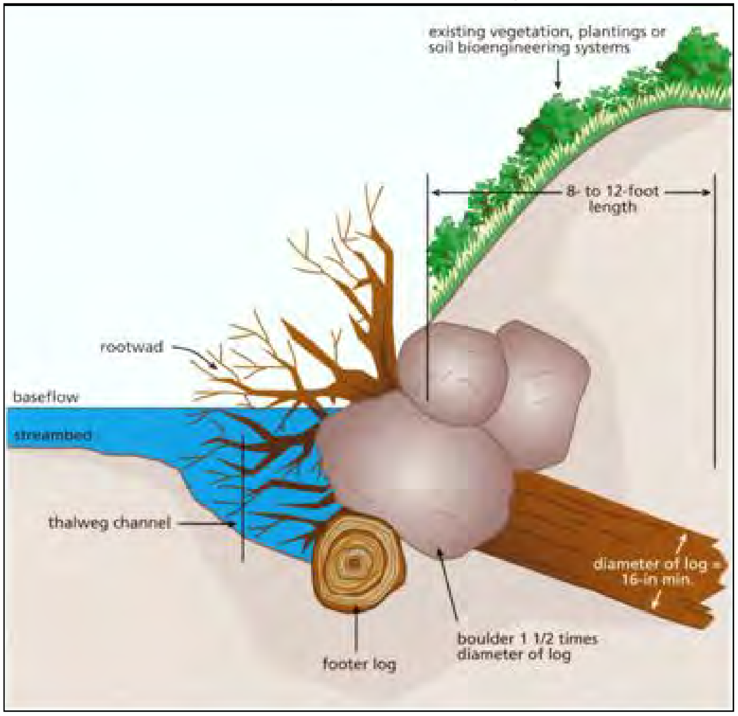


Figure 7-26. Root Wad Revetment

Photograph 7-24. Bankline Stabilization

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

b. Case Studies None Listed.

22. Woody Debris. 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 (Fischenich and Morrow, 2000).

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.

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 7-27).

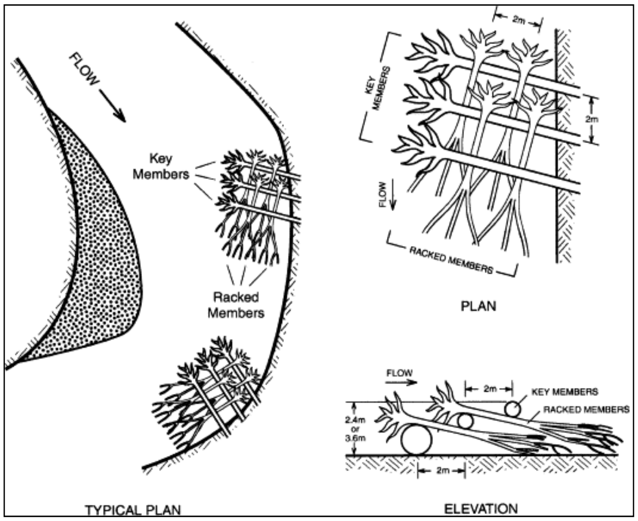


Figure 7-27. Woody Debris

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.

a. 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.

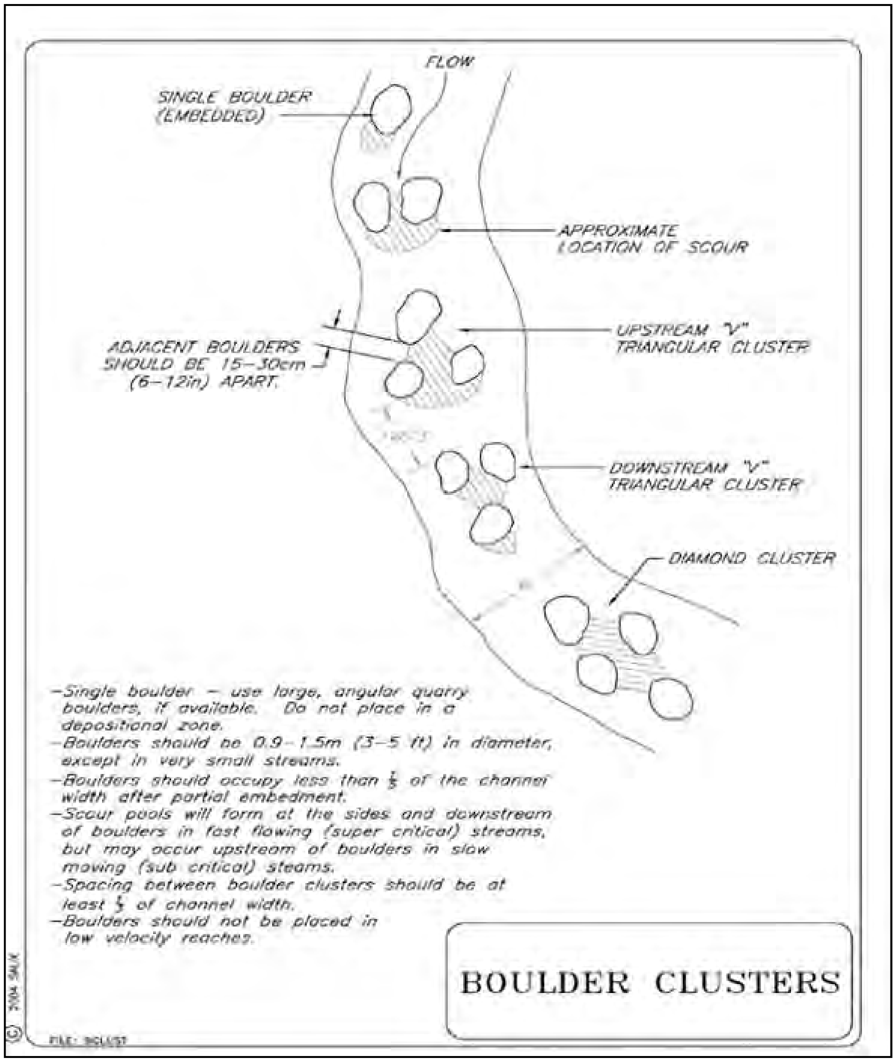
b. Case Study

Large wood bundles have been placed in numerous scour holes in several side channels of the Middle Mississippi River (photograph 7-25)

Photograph 7-25. Wood Bundles

23. Boulder Clusters. 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 (Derrick, 2005).

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 7-28).



- Single boulder – use large, angular quarry boulders, if available. Do not place in a depositional zone.
- Boulders should be 0.9–1.5m (3–5 ft) in diameter, except in very small streams.
- Boulders should occupy less than $\frac{1}{5}$ of the channel width after partial embedment.
- Scour pools will form at the sides and downstream of boulders in fast flowing (super critical) streams, but may occur upstream of boulders in slow moving (sub critical) steams.
- Spacing between boulder clusters should be at least $\frac{1}{5}$ of channel width.
- Boulders should not be placed in low velocity reaches.

Figure 7-28. Boulder Clusters

a. 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 downstream of the cluster if not designed properly. If the rock cluster is too high, they can provide perches for predators and/or fishermen.

b. Case Study

Eighteen Mile Creek Salmon Stream Restoration, Newfane, NY (photograph 7-26)

Photograph 7-26. Boulder Clusters

24 Fish LUNKERS (Little Underwater Neighborhood Keepers Encompassing Rheotactic[2] Salmonids). 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 feet long, 1 to 2 feet tall, and 3 feet 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 feet 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 7-29).

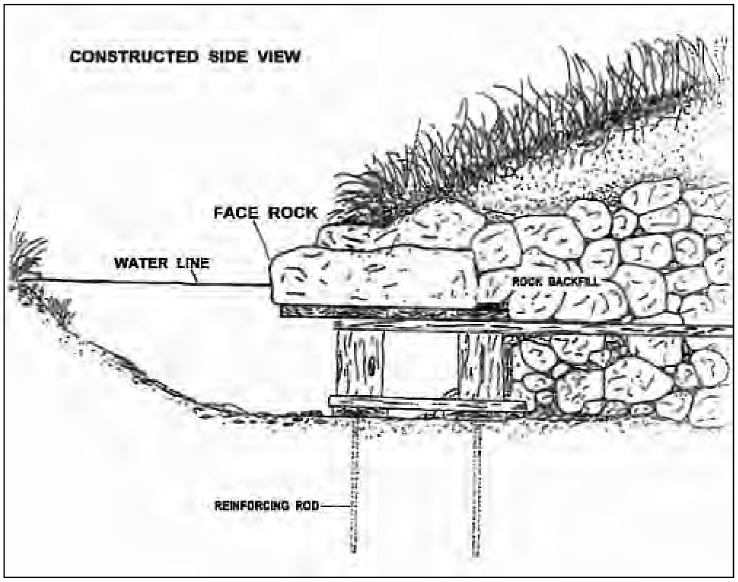


Figure 7-29. Fish LUNKER

a. 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 sufficient velocities to scour overhang area; reinforcing the foundation; and the low-flow water surface elevation to be on the header board.

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[2] Rheotactic - fish that prefer to face into the current

b. Case Study

Eighteen Mile Creek Salmon Stream Restoration, Newfane, NY (photograph 7-27)

Photograph 7-27. Fish LUNKER

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