UPPER MISSISSIPPI RIVER SYSTEM
ENVIRONMENTAL MANAGEMENT PROGRAM
DESIGN HANDBOOK

CHAPTER 9

ISLANDS

APPENDIX C
ENGINEERING CONSIDERATIONS

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Engineering Consideration 1: Shoreline Stabilization 9-C-1
Engineering Consideration 2: Reducing Sediment Loads But Increasing Sediment Trap Efficiency .. 9-C-4
Engineering Consideration 3: Island Elevations And Bankfull Flood Elevations in Lower Pools 9-C-5
Engineering Consideration 4. Wind-driven Wave Action 9-C-7
Engineering Consideration 5: Island Width Versus Stability 9-C-10
Engineering Consideration 6: Beach Formation Process 9-C-11
Engineering Consideration 7: Wood Species for Biotechnical Stabilization 9-C-13
Engineering Consideration 8: Seepage Through Rock Structures 9-C-13
Engineering Consideration 9: Displacement of Sediments 9-C-14

Tables

9.C.1 Erosion and Stabilization Assessment Worksheet 9-C-1
9.C.2 Shoreline Stabilization Designs Recommended for Islands 9-C-2
9.C.3 Properties of Wood 9-C-13

Figures

9.C.1 Berm Width Versus Wind Fetch and Water Depth 9-C-3
9.C.2 Suspended Sediment Data Showing Relatively Low Concentrations 9-C-4
9.C.3 Impacts of Wave Velocity Created by Wind Fetch With and Without Island Protection 9-C-8
9.C.4 Change in Fetch in Lower Pool 8 ..... 9-C-10
9.C.5 Reshaping of the Islands Shoreline Due to Wave Action 9-C-12

Photographs

9.C.1. Lake Onalaska, Pool 7 ..... 9-C-4
9.C.2. Pool 8, Phase I, Stage II, Grassy Island 9-C-11

APPENDIX C
ENGINEERING CONSIDERATIONS

Engineering considerations are a broad category of knowledge relating to the physical response, impacts, or properties of islands and associated structures. After goals and objectives for a project have been set, they are considered for identifying actions and measures, establishing design criteria, and developing plans and specifications. Most of the engineering considerations listed here are based on knowledge of river mechanics and sediment transport. They may have been extracted from engineering manuals and adapted to island design or they could represent a summary of engineering analysis that has been done for island projects.

Engineering Consideration 1: Shoreline Stabilization. Shoreline stabilization for islands should be designed using the following steps:

1. Determine if stabilization is needed by doing an erosion assessment using the score sheet shown in table 9.C.1. First-hand knowledge of erosion problems should supersede this assessment.

Table 9.C.1. Erosion and Stabilization Assessment Worksheet

Erosion & Stabilization Assessment Worksheet

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

Total Score >18, Bank Stabilization Needed
Total Score = 12 to 18, Further analysis needed
Total Score < 12, Bank Stabilization Not Needed

Reach Descriptions
Reach 1 -
Reach 2 -
Reach 3 -

2. Decide which of two approaches will be used to deal with erosion. The first approach is to harden the shoreline with additional rock, or in some cases increased vegetation, to make it more resistant to erosion. The second approach is to eliminate or reduce the magnitude of the erosive force so that the shoreline in its existing condition will not erode. This can be done by establishing woody vegetation on the berms, by building offshore structures of rock or wood, or by spacing islands so that wind fetch is kept to an acceptable level.

3. Use the information in table 9.C.2 to determine what type of stabilization to use.

Table 9.C.2. Shoreline Stabilization Designs Recommended for Islands

Erosion Process	Nearshore Bathymetry	Marine Plant Access	Stabilization Design
River Current	deep (> 3')	yes	Revetment Vanes
		no	Revetment Vanes
	shallow (< 3')	yes	Revetment Vanes Off-Shore Mounds Vegetation
		no	Revetment Vanes Off-shore mounds Vegetation
Waves	deep (> 3')	yes	Revetment
		no	Revetment
	shallow (< 3')	yes	Groins Rock Wedge Vegetation
		no	Groins Offshore Mound Rock Wedge Vegetation

4. Use figure 9.C.1 to determine berm width. Adequate material must be provided in the berm so that some of the berm material can be eroded during beach formation, and leave at least 15 feet of berm width so that a swath of woody vegetation will protect the main part of the island. Woody vegetation provides rigid stems which protects the main part of the island during floods.

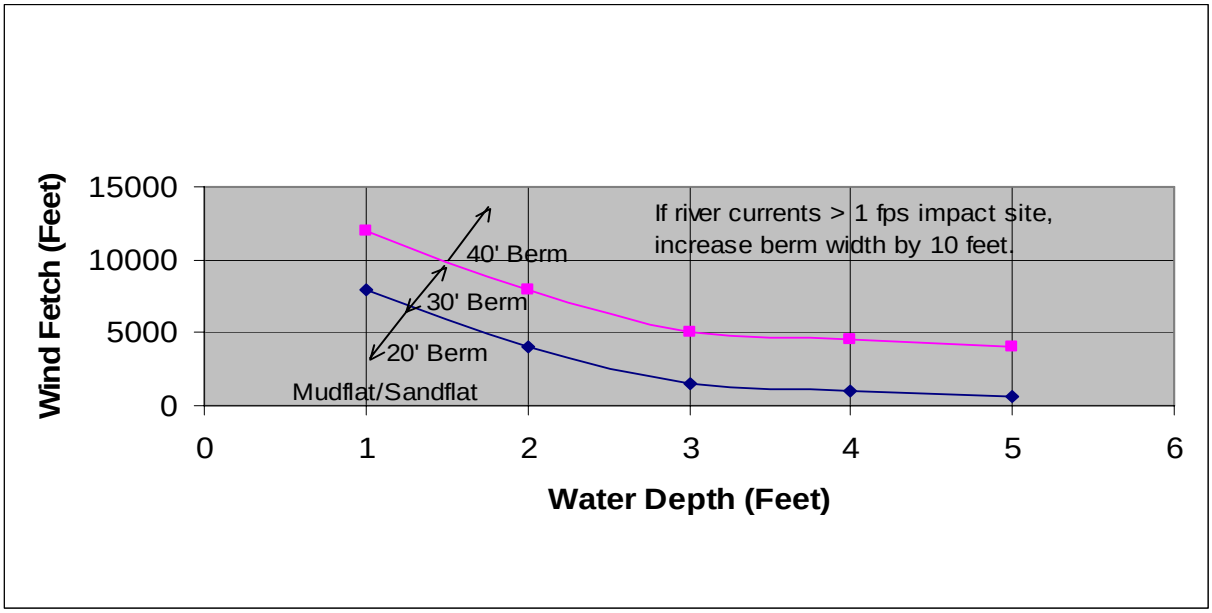

Figure 9.C.1. Berm Width Versus Wind Fetch and Water Depth

5. On shorelines that are extremely sheltered, use vegetative stabilization.

6. On shorelines exposed to significant wave action, rock groins are constructed perpendicular to the berm to prevent longshore transport of sand. Groins are usually 20 to 40 feet long, have a 3 foot top width, 1V:1.5H side slopes and are spaced at a distance equal to 6 times the groin length. Offshore rock mounds can be used instead of groins to add diversity to an island shoreline or if shallow depths inhibit access to the shoreline by construction equipment. Rock mounds only need a top elevation at or just above the average water surface to act as wave breaks, however they are usually constructed to an elevation 2 to 3 feet over the average water surface to account for settlement and sluffing due to wave and ice action. Rock mounds are very expensive to construct.

7. On shorelines where river currents are the primary erosive force, the same berm design as described above can be used except that vanes are used instead of groins. Vanes redirect river currents and move erosive secondary flow cells away from the shoreline. Vanes are 30 to 50 feet long, have a 3 foot top width, 1V:1.5 H side slopes and are spaced at a distance equal to 4 times the vane length. Vanes are angled upstream 30 to 45 degrees with the shoreline and decrease in elevation from 2 feet above the average water surface at the shoreline to 1 foot below the average at the riverward end.

8. The potential for ice action seems to be proportional to the size of the water body. Large backwaters like Lake Onalaska, produce the most problems. Ice action can occur due to freeze thaw expansion of the ice pack or due to wind stresses during breakup. If severe ice action occurs in the project area, berm width should be increased, rock size increased, and rock slopes flattened. Groins should not be used, as they are too easily damaged by ice (photograph 9.C.1) .

Photograph 9.C.1. Lake Onalaska, Pool 7. These groins were constructed so that they extended into the water 30 feet. Ice action pushed the rock on to the beach.

Studies done at the Corps of Engineers' Cold Regions Laboratory recommended maximum rock sizes 2.5 times the average ice thickness and rock slopes of 1V:3H or flatter, if ice conditions are severe (Sodhi, 1997). Problems occurred at the Lake Onalaska island project when ice action displaced riprap which had been constructed at a 1V:3H slope. These problems were compounded by the fact that the berms on these islands were only 20 feet wide. Based on this experience, if ice action is expected to be a problem, rock features should be constructed with 1V:4H slopes or flatter and berm widths should be increased to 40 feet or more.

Engineering Consideration 2: Reducing Sediment Loads But Increasing Sediment Trap Efficiency. Islands reduce the flow of water and sediment to backwater areas or selected parts of backwater areas. This decreases flow velocities, which is usually a necessary step in improving habitat. However, the trap efficiency of the backwater area sheltered by the island is increased so sediment that does enter is more likely to deposit there. This is compounded by the fact that wind-driven wave action and sediment resuspension, which results in export of sediment from backwaters, is also reduced. In-other-words, an island project may have reduced the sediment input to an area, but the sediment removal mechanisms, river currents and wave action, have also been reduced. Objectives for more recent projects recognize this fact and include features such as rock sills, and strategically placed islands to manage deposition and erosion so that habitat is diversified and sustained. The only way to maintain floodplain depth is to completely eliminate the supply of sediment (which is rarely an option)

or to construct islands at a low enough elevation so they are overtopped by annual floods, which potentially could scour sediments from the backwater. This takes advantage of the fact that the sediment-discharge relationship in pools 1-10 is relatively flat at higher discharges (figure 9.C.2). This occurs because the sediment transport load is supply-limited, resulting in low sediment concentrations during floods. Sediment concentrations peak near the bankfull discharge and remain steady or sometimes decrease from this point on. By choosing low top elevations, the clean water that occurs at higher discharge is conveyed over the island and through the project area, potentially scouring accumulated sediments carrying them out of the backwater or redistributing them. Recent island projects (Pool 8 Phase II and Polander Lake) have been constructed to lower elevations. The Pool 8 Phase II project included rock sills constructed to about the 2-year flood event and interior islands which force water to move through deeper channels.

Engineering Consideration 3: Island Elevations And Bankfull Flood Elevations in Lower Pools. River restoration efforts usually attempt to establish riverine flow conditions where flow is conveyed in channels for low and moderate flows and significant floodplain flow occurs only after the bankfull flood level is exceeded. Islands, in their most basic form, are the natural levees that separate channels from floodplains. It follows that island height should correspond to bankfull flood levels if the goal is to mimic natural conditions. However, in the lower ends of many of the pools, the elevation that corresponds to a bankfull discharge is often less than the low flow elevation due to the way the locks and dam are operated. Constructing an island this low eliminates any chance of maintaining grass cover on the island since woody vegetation quickly takes over. Also, the operation of construction equipment could be more difficult on a surface this close to the water elevation. For this reason, island elevations are usually higher than bankfull. Low elevation rock sills can be incorporated into the design to increase the amount of floodplain flow. However even these structures usually end up being higher than the bankfull flood event because of habitat considerations in the project area. For instance, creating the low flow conditions for over-wintering fish habitat usually results in the rock sills being set at a higher elevation than bankfull to minimize the chance overtopping during late fall high water events.

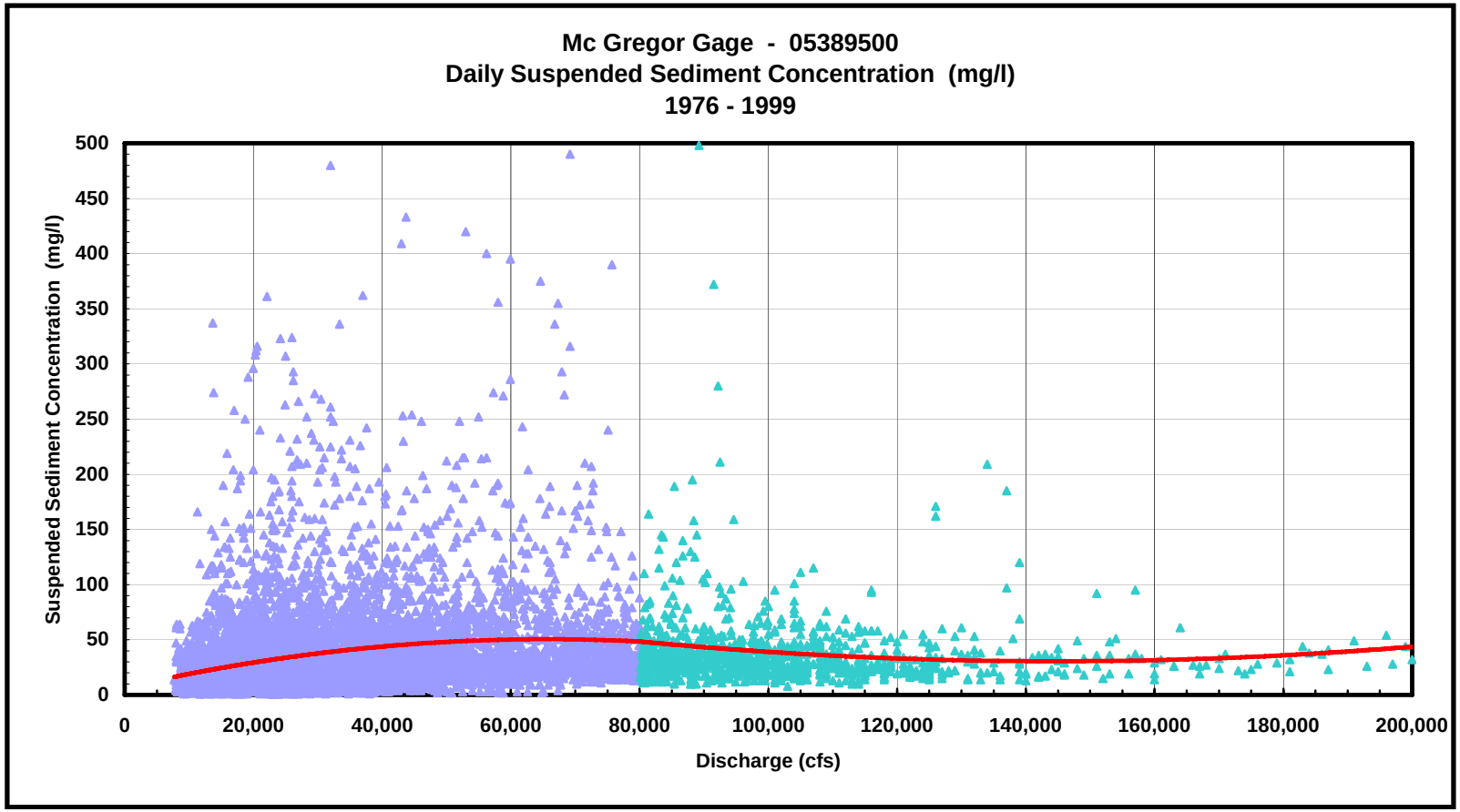

Figure 9.C.2. Suspended Sediment Data at McGregor, Iowa Showing the Relatively Low Concentrations That Occur at Higher Discharges

Engineering Consideration 4. Wind-driven Wave Action. Islands effectively reduce wind driven wave action and the resuspension of sediment by waves up to 1 mile downwind of the island. As wind is deflected up and over an island and its trees, a sheltered zone is created on the downwind side of the island. This zone is roughly 10 times the height of the island and its trees (Ford and Stefan, 1980). The value of this sheltered zone hasn't been stated in a quantitative fashion, however providing thermal refuge for migrating waterfowl is a desirable outcome of island projects. This sheltered zone should contain aquatic plants, invertebrates, and other forms of food for it to be of value, which is another reason to position islands so they shelter shallow water.

Beyond the sheltered zone, waves start building as wind exerts shear stress on the water surface. Each wave creates an orbital motion in the water column resulting in a bottom velocity and shear stress. If this shear stress exceeds the critical shear stress for particle erosion, sediment is resuspended. Data collected in Weaver Bottoms (Nelson, 1998) indicated a strong relationship between wind and suspended sediment concentrations for low flow conditions but a much weaker relationship as flows approached the bankfull flow event. This transition from Lacustrine to Riverine conditions was due to the increased flow through Weaver Bottoms and higher water levels, which decreased the impacts of wave action on the bottom. A rule of thumb used is that the bottom velocity and shear stress generated by wave action should be less than one half the velocity and shear stress created by flood flows. A wind fetch of 4000 to 5000 feet or less is usually recommended to achieve this. For instance, a wind fetch of 5000 feet, wind speed of 20 mph, and water depth of 3 feet, results in bottom velocities due to wave action of around 0.45 fps (compared to measured velocities during floods that usually approach 1 fps). Other factors such as bathymetry and the location of historic islands usually affect position and spacing as much as the fetch guidance. This is illustrated in figure 9.C.3.

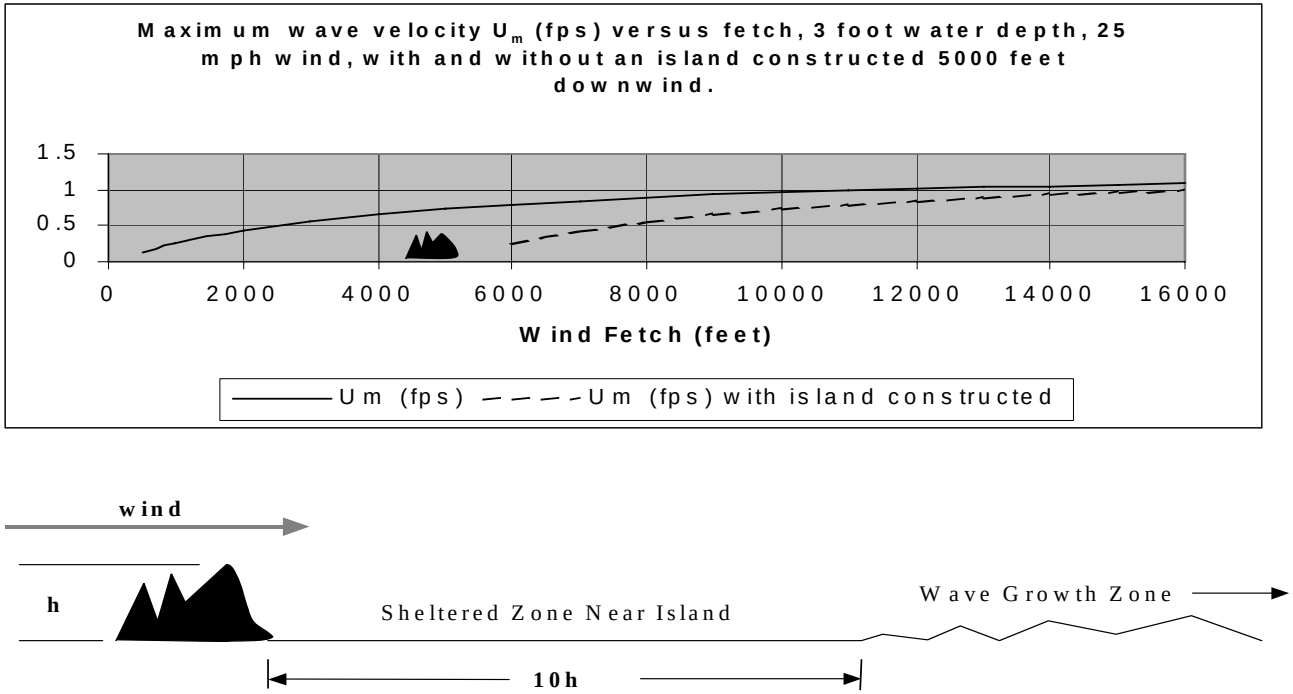

Figure 9.C.3. Impacts of Wave Velocity Created by Wind Fetch With and Without Island Protection

While the rule of thumb given above is adequate for initial planning, island spacing and layout should take into account local bathymetry. As the water depth gets shallower, waves have a greater impact on the bottom. To account for this, the bottom shear stress generated by waves should be determined and compared to a critical shear stress for sediment resuspension. The following equations can be used to calculate wave height, period, and length for deepwater waves, maximum orbital wave velocity, and bottom shear stress. Waves in shallow UMRS impoundments are usually transitional in nature, but the deepwater equations usually do a better job of predicting wave height. Further detail regarding the development of these equations can be found in LTRM Special Report 94-S001 (Chamberlin, 1994).

$$H = .0016\, U_A\, (F/g)^{1/2}$$

$$T = .286\, F^{1/3}\, U_A^{1/3} / g^{2/3}$$

$$L = g\, T^2 / 2\pi$$

$$u_m = \pi H / (T \sinh (2\pi\, d_f / L))$$

$$\tau = \rho\, f\, u_m^2 / 2$$

Where:

H = wave height (meters)
U_A = wind speed (meters/second)
F = wind fetch (meters)
g = acceleration of gravity (9.82 meters/second)
T = wave period (seconds)
L = wave length (meters)
u_m = maximum orbital wave velocity at the bottom (meters/second)
d_f = water depth in the floodplain (meters)
τ = shear stress at the bottom (Newtons/square meter)
ρ = density of water (Kg/m3)
f = friction factor (assumed to be .032)

The value of the critical shear stress for sediment resuspension depends on sediment characteristics such as particle size and cohesiveness, and on aquatic vegetation. Usually there is very little information on sediment properties and the amount of aquatic vegetation varies from year to year. A value of .01 psf seems to match conditions in backwater areas fairly well. For instance, using the deep water wave equations, and assuming a wind speed of 20 mph, the wind fetches that result in a bottom shear stress that exceeds the assumed critical shear stress for sediment resuspension of .01 psf are as follows:

Water depth (feet)	1	2	3	4
Deepwater Fetch (feet)	1500	3500	6000	9000

These wind fetch values could be used as a guide in laying out islands.

The series of images below (provided by Jim Rogala, UMESC, 2005) shows the change in wind fetch in lower pool 8 through time. Wind direction data based on historical frequency of occurrence during the open water period was used to create a weighted fetch coverage. The reduction in wind fetch shown over the last three images are due to island construction in lower Pool 8 through the EMP. The reduction in fetch from 1989 to 1998 is due to the construction of Phase I and Phase II of the Pool 8 Island project. The reduction in fetch from 1998 to 1999 is due to seed island construction. The reduction illustrated from 1999 to 2007 is the expected impact of the Phase III portion of the Pool 8 Island project. A change in fetch is shown in figure 9.C.4.

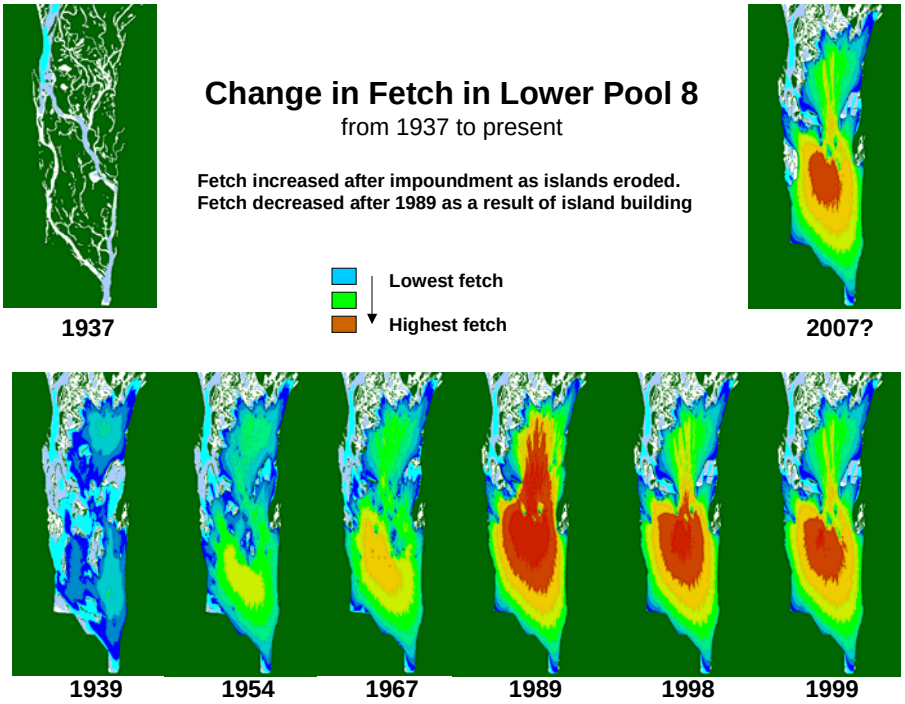

Figure 9.C.4. Change in Fetch in Lower Pool 8

Engineering Consideration 5: Island Width Versus Stability. The hydraulic slope, flow velocity, and potential for erosion decreases with increased island width. The range of widths used on previous projects (70 to 200 foot base width) has resulted in stable islands in all cases. This suggests that island width can be at the lower end of this range, however, the headloss across the island and frequency of overtopping must be considered. Generally, lower sections of island that are overtopped first should be wider than higher sections.

Burrows of animals (mostly muskrats) and subsequent tunnel collapse during Spring highwater conditions results in small trenches that may extend up to 20 feet in from the shoreline. The concern with this is that these trenches could be erosion sites during an overtopping event. This has never been a problem on the wide islands that have been constructed, however it could be a problem if island width was reduced too much.

The present state of island design has focused on meeting aquatic goals and objectives through the construction of the most cost effective and stable island design. However, future island projects that incorporate sand/mudflats, isolated wetlands, and more terrestrial habitat goals and objectives would warrant the construction of islands with larger footprints to meet the terrestrial and other habitat objectives.

Engineering Consideration 6: Beach Formation Process. When sand is placed for the island base, two wind-driven processes begin acting. The first is littoral drift, which is the process of sand moving down a shoreline in response to the angle that waves approach a shoreline from the predominant wind direction. Groins are usually constructed to stop this process, resulting in the scalloped shoreline shape (photograph 9.C.2). This photo shows Grassy Island a couple of months after construction. Wave action and littoral drift have caused the scalloped shape seen here. Sand is eroded from the area between each set of groins and deposits near the groin.

Photograph 9.C.2. Pool 8, Phase I, Stage II, Grassy Island

The second process is beach formation, which results from a combination of offshore transport of sand and from berm erosion due to wave action. Surveys of island shorelines indicate that a beach with a slope of 1V:8H to 1V:12H will eventually be created. The initial berm profile and the final profile are illustrated in figure C.5. Enough material must be placed in the berm so that after the beach formation process has occurred at least 20 feet of berm will remain upon which willows and other woody vegetation can grow. As an example, if the water depth is 3 feet and the beach slope is 1V:10H, a 30 foot wide beach will form. Roughly half of the berm will erode during this process. So with 15 feet of berm erosion, the initial berm width should have been 35 feet for 20 feet of berm to remain.

Wave action results in offshore transport of sand until a stable beach slope is achieved. The as-built berm width, is reduced because of this. The final beach slope varies but a typical value is 1V:10H.

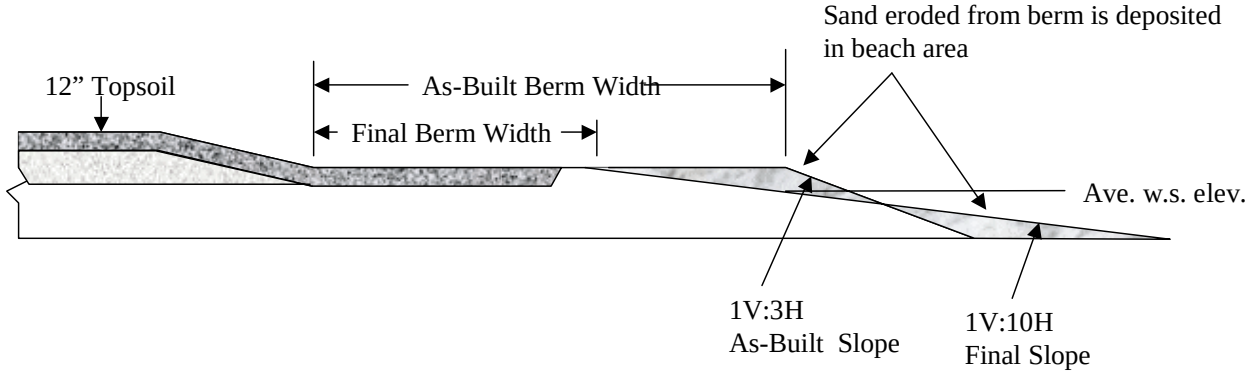

Figure 9.C.5. Reshaping of the Islands Shoreline Due to Wave Action

Engineering Consideration 7: Wood Species for Biotechnical Stabilization. Placing logs along island shorelines or incorporating them into shoreline stabilization structures is desirable from the standpoint of habitat (fish structure, loafing structure and substrate) and aesthetics. Logs with a high specific weight and high decay resistance are desirable since they resist the buoyant forces exerted on them and they will last longer. An excellent reference on large woody debris structures is Shields, et al. (2004). This reference discusses in detail design procedures, costs, and successes of woody debris structures. The information in table 9.C.3 on wood density and decay resistance was developed by the St. Paul District's Natural Resources Office. Black Locust is the most desirable species since it is relatively heavy, decay resistant, and is an undesirable non-native species that is frequently harvested because it tends to dominate forests once it becomes established.

Table 9.C.3. Properties of Wood
Information provided by Randy Urich, Forester, St. Paul District Natural Resources Office

Species	Weight per Standard Cord (pounds)	Weight per Cubic Foot (green)	Decay Resistance
Ash, white	4300	48	Low
Aspen	-	-	Low
Black cherry	4000	45	High
Black locust	5200	58	Exceptionally
Black walnut	5200	58	High
Cottonwood	4400	49	Low
Elm	5000	54	Low
Hackberry	4500	50	Low
Hickory	5700	63	Low
Honeylocust	5500	61	Moderate
Red Cedar	3300	37	High
Silver maple	4300	45	Low
Red oak	5700	64	Low
White oak	5600	63	High

From the standpoint of longevity, it is desirable to place the logs so that they are either above or below the water surface the majority of the time to avoid decay associated with wetting and drying. However, the guidance on habitat loafing structures (habitat parameter 5) should be used to optimize log placement.

Engineering Consideration 8: Seepage Through Rock Structures. Excessive seepage through the voids in rock structures is a concern because of the potentially negative impacts on over-wintering fish habitat. An impervious fabric was included in the rock sills at the Pool 8, Phase II project to reduce seepage, however this nearly doubled the cost of these rock sills. Natural plugging of the voids in rock structures has been documented in the past, however there are other cases where seepage seems to occur for years after the structure is constructed. There doesn't seem to be a consistent set of lessons learned regarding seepage, so it is something that design teams must take into account on a case-by-case basis.

Engineering Consideration 9: Displacement of Sediments. Displacement (or rapid settlement, which occurs during construction) occurs on every project to some extent. The Corps' standard method of measuring displacement is settlement gages, however these don't work for islands built hydraulically because they are always tipped over by the mud wave in front of the sand. At the Trempealeau National Wildlife Refuge (NWR), which involved construction of a dike in open water similar to what is done for islands, displacement of 1.25 feet was measured using post construction borings. The method of hydraulic placement of sand had to be altered to reduce the size of the mud-wave, which inhibited continued placement of sand. The technique ultimately used, involved placing the sand in a wedge-shaped fashion.