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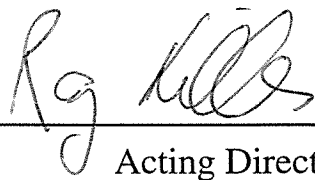
**RECOMMENDED GUIDELINES FOR
DEVELOPING BANK STABILIZATION
FACILITIES OF RIVERS IN
WESTERN WASHINGTON**

**FEDERAL EMERGENCY MANAGEMENT
AGENCY (FEMA), REGION X**

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Approved

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Acting Director

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KEY WORDS

bank stabilization, cross-section, discharge, fish habitat, Federal Emergency Management Agency (FEMA), guidelines, Stillaguamish River, western Washington

INTRODUCTION

The recommended Federal Emergency Management Agency (FEMA) guidelines are designed to assist applicants and inspectors in developing plans for bank facilities for stabilizing and restoring damaged stream banks. The guidelines were developed because many of the bank locations previously restored through FEMA participation suffer from repetitive damage during each flood disaster event. Much of this repetitive damage results from the fact that stream banks are repaired with little regard to the prevention of future damage. In many cases, where the bank has been damaged, the damage is repaired by local agencies dumping some dirt or gravel in the damaged area, smoothing it out, and revegetating or placing rock if deemed desirable or necessary. Frequently, little consideration is given to the hydraulic conditions, to a reasonable slope, the need for filter cloth, the precise placement and size of riprap, fish habitat requirements, etc. To address this situation, FEMA established a contract with the University of Washington School of Fisheries to assist them in developing guidelines for bank stabilization facilities

The recommended FEMA guidelines allow the incorporation of fish habitat components within bank stabilization facilities. Fish habitat components are defined for two habitat categories, *bank protection* and *bank cover*, as designated by the Washington Department of Fish and Wildlife (WDFW). The guidelines only pertain to bank-placed or bank-anchored facilities that can stabilize banks. Instream channel facilities and fish habitat components are not included in the guidelines. However, the guidelines do provide opportunities for creating additional fish habitat. Potentials for compensatory flow, which give a channel greater flow alternatives during peak flows, can provide additional fish habitat by allowing habitats to vary spatially during different seasons of the year. Such habitat opportunities can enhance fish survival during different life-cycle stages (e.g., rearing habitat for juveniles and spawning habitat for adult fish).

GUIDELINES FOR DESCRIBING DAMAGED BANK SITES

The objective of describing a damaged site is to produce for the FEMA application the documentation of (1) the site characteristics prior to installing any bank facility, and (2) the types of information to be used in the design of a bank stabilization facility. The survey can be completed by answering questions about the site's geomorphic location in the drainage, hydrologic regime, and cross-sectional characteristics. The answers are produced by using US Geological Survey (USGS) discharge records and establishing cross-sections to obtain bank and channel data. The cross-sections need to be established at the damaged site and at several adjacent upstream and downstream sites within the same reach. In general, the separation distance between cross-sections can range from two to four channel widths depending on variations in channel and reach characteristics (Water Resources Council 1976, French 1985). The reach, cross-section locations, and damaged bank areas should be mapped in detail by plane-table methods (Water Resources Council 1976, Newbury and Gaboury 1991). A useful software tool for analyzing cross-sections can be obtained from the Bureau of Land Management (Grant et al. 1992).

The applicants need to provide answers in the same formats as shown by the guideline examples (i.e., answers). The examples are for cross-sections of a reach with a moderate channel slope (0.024) at river mile (rm) 34 on the North Fork of the Stillaguamish River. The cross-sections were established by Collings and Hill (1973).

WHAT ARE THE GENERAL REACH CHARACTERISTICS OF THE DAMAGED BANK SITE?

The reach characteristics of bank sites need to be determined by identifying the geomorphic province of the reach and bank site. River drainages in western Washington commonly contain three types of geomorphic provinces: (1) sediment deposition, (2) sediment transport, and (3) the sediment supply (Montgomery and Buffington 1993). These provinces are characterized by different ranges of channel gradients, bottom substrate sizes, and habitat or channel types (Fig. 1). In most situations, sites eligible for FEMA consideration lie within the first two geomorphic provinces, *sediment deposition* ('low gradient') and *sediment transport* ('moderate gradient'). The sediment supply province ('high gradient') of upstream and smaller drainage areas usually occurs within the jurisdiction of the National Resources Conservation Services (NRCS).

The general characteristics of each geomorphic province include the following:

- *sediment deposition province*
low gradient channels (<0.001)
fine sediments (0.0025- to 0.08-inch diameter)
regime-type habitats
- *sediment transport province*
moderate gradient channels (0.001 to 0.10)
moderate to coarse substrates (0.16- to 10-inch diameter)
steep-pool, plane-bed and pool-riffle habitats
- *sediment supply province*
high gradient channels (>0.10)
large-sized substrates (>10-inch diameter)
cascade and steep-pool habitats

Bank sites that are located within the sediment transport province should be expected to offer greater options for including fish habitat components when installing bank stabilization facilities. The sediment transport province contains a wide range of channel gradients, substrate sizes, and habitat types (steep-pool, plane-bed, and pool-riffle).

The sediment deposition province can be expected to offer fewer opportunities for including fish habitat components within bank stabilization facilities. Such low-gradient provinces usually experience high deposition of fine sediments, which can bury fish habitat components.

Answer: The general reach characteristics of the potential bank site ("damaged") of the North Fork of the Stillaguamish River (rm 34) indicate that the site lies within a sediment transport province. The general reach characteristics include a channel gradient of 0.024, dominated by pool and riffle habitats.

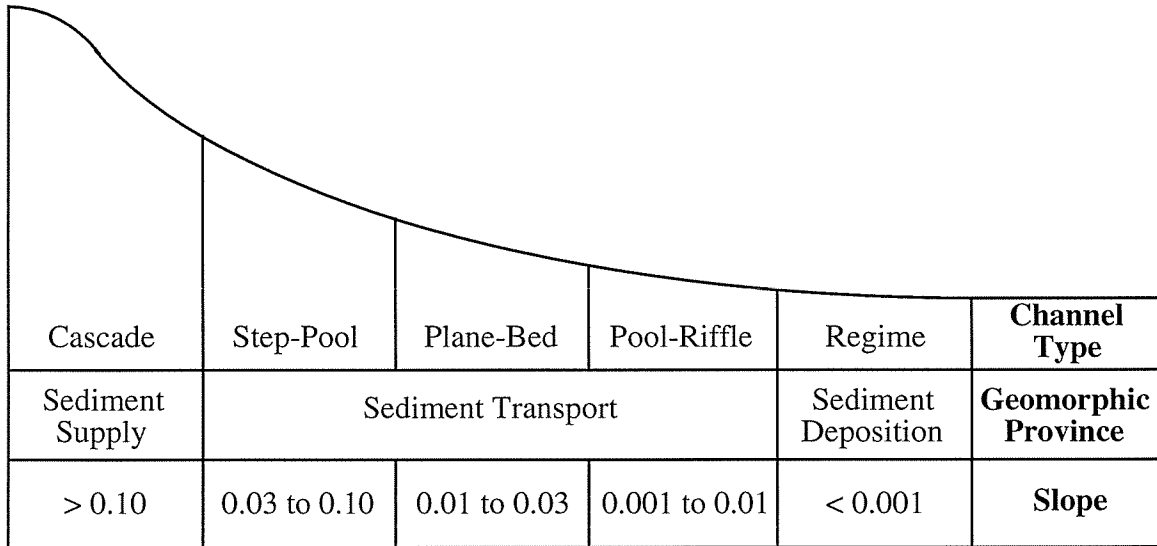


Figure 1. Geomorphic provinces: Sediment deposition, transport, and sediment supply provinces of river drainage basins in western Washington. Provinces characterized by different ranges of channel gradients, bottom substrate sizes, and habitat types (adapted from Montgomery and Buffington 1993).

WHAT IS THE POTENTIAL BANKFULL DISCHARGE RATE (CFS) AT THE DAMAGED BANK SITE?

Answer: An approximation of bankfull discharge can be obtained using a drainage area to bankfull relationship for different West Cascade and Puget Sound river drainages (Dunn and Leopold 1978). The equation is

$$Q_{BF} = 55 D_A^{0.93} \quad (1)$$

where Q_{BF} is the bankfull discharge (ft³/sec, cfs) and D_A is the drainage area (mi²). The bankfull discharge rate for the North Fork of the Stillaguamish River reach (rm 34 with an upstream drainage area of 162 mi²) is 6,604 cfs. The applicants should be aware that when the discharge of a river drainage is subjected to flow regulation (e.g., Green and Cedar rivers), the use of the drainage-area-to-bankfull relationship of Dunn and Leopold (1978) is questionable.

WHAT ARE THE POTENTIAL DISCHARGE RATES FOR 2-, 5-, AND 100-YR FLOOD RECURRENCE INTERVALS AT THE DAMAGED SITE?

Answer: This question can be answered using USGS discharge records from gauging stations within the river drainage of interest. For the North Fork of the Stillaguamish River (gauging station 12167000, rm 6.5), the discharge rates for the 2-, 5-, and 100-yr flood recurrence intervals are 21,093 cfs, 26,835 cfs, and 39,134 cfs, respectively (Fig. 2). This flood recurrence information was obtained from the USGS Open-File Report 84-144-B (Williams et al. 1985) and Water Resources Council (WRC) estimates (Water Resources Council 1976).

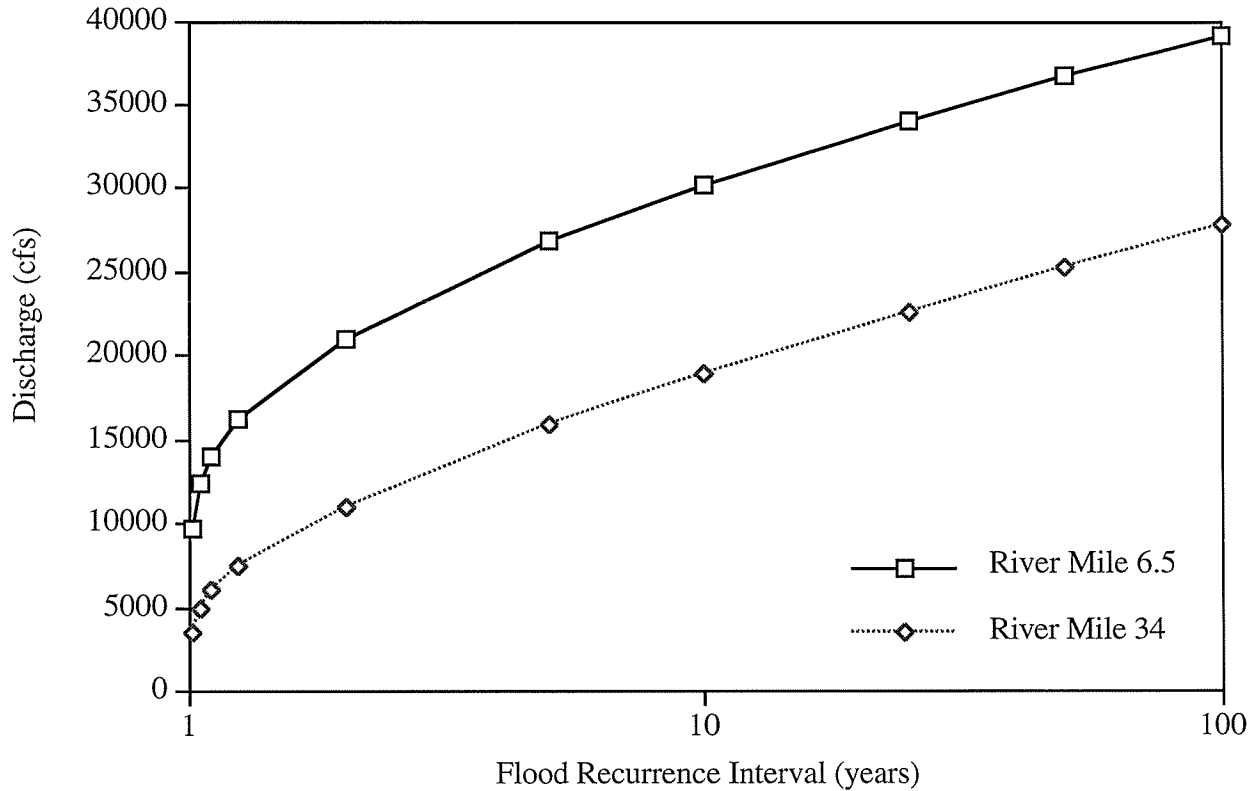


Figure 2. Discharge rates and flood recurrence intervals at river mile (rm) 6.5 and 34 on the North Fork of the Stillaguamish River, Washington. The bold line indicates the discharge rates (cfs) at gauging station 12167000 (rm 6.5). The discharge rates for the 2-, 5-, and 100-yr flood recurrence intervals are 21,093 cfs, 26,835 cfs, and 39,134 cfs, respectively. The line representing the lower discharge rates is potential discharge rates and flood recurrence intervals at a “damaged site” (rm 34). The discharge rates for the 2-, 5-, and 100-yr flood recurrence intervals are 11,093, 15,879, and 27,859 cfs, respectively. These discharge rates at rm 34 were determined using a stage discharge relationship established by Collings and Hill (1973).

From the applicant’s standpoint, the available gauging station data usually apply to drainage areas larger than the areas of concern. For example, the discharge rates for the gauging station 12167000 represent a drainage area of 262 mi² that is 1.6 times greater than the drainage area (162 mi²) for the damaged site (rm 34, North Fork of the Stillaguamish River). Such differences in drainage areas necessitates that discharge rates be made from a stage discharge relationship (Dunn and Leopold 1978). Direct flow observations need to be made as close as possible (e.g., cross-sections) to the damaged site to establish a stage discharge relationship. These observations involve a staff gauge, a cross-section, and a relationship of the reading of water surface elevation on the staff gauge to simultaneous discharge estimates derived from cross-sectional areas and water velocities. Discharge rates at the damaged bank site can be estimated from cross-sectional characteristics and water velocity measurements (Dunn and Leopold 1978). The equation is:

$$Q = A\mu \quad (2)$$

where Q = estimated discharge (cfs),
 A = cross-sectional area (ft²), and
 μ = velocity (ft/sec).

In natural channels, velocity as well as depth and width increases as discharge increases. An example of cross-sectional data for the reach and bank site on the North Fork of the Stillaguamish River is shown in Table 1. Water velocities should be measured with a current meter during different flow periods.

Collings and Hill (1973) used a regression analysis to determine a stage discharge relationship established from a staff gauge and flow measurements for the downstream cross-section (cross-section 3, Table 1) at rm 34 on the North Fork of the Stillaguamish River. The discharge relationship is

$$Q_D = 0.004 (Q_G)^{1.49} \quad (3)$$

where Q_D is estimated discharge (cfs) at the damaged sites and Q_G is the discharge at gauging station 12167000. The relationship between the discharge at the damaged site (Q_D) and the discharge at the gauging station (Q_G) make it possible to evaluate the frequency of discharges at the damaged bank site based on the long-term record at the gauge. For the North Fork of the Stillaguamish River (rm 34), the discharge rates for the 1.1-, 2-, 5-, and 100-yr flood recurrence intervals are 6,061 cfs, 11,093 cfs, 15,879 and 27,859 cfs, respectively (Fig. 2). The 2-yr flood level (11,093 cfs) indicates that this discharge level can be expected to occur once in 2 yr on the average. Accordingly, the bankfull discharge (6,604 cfs) might be expected to occur once in 1.2 yr.

The discharge rates and flood recurrence intervals of the stage discharge relationship provide the first approximation of potential design requirements for the bank stabilization facility. The facility should be able to accommodate peak flows that exceed the bankfull discharge rates. The maximum stage heights should not exceed the base elevation of a levee or potential levee and revetment sites.

Table 1. Example of cross-sectional data and estimates of channel conveyances (K) for the North Fork of the Stillaguamish River at river mile 34 (Collings et al. 1973). Data for the downstream section 3 is from Collings 1973. The upstream sections 1 and 2 are approximations of cross-sectional areas (A). The value n represents an approximation of the total Manning roughness coefficient for the channel boundaries.

Cross-section	Slope (S) (ft)	Width (w) (ft)	Depth (d) (ft)	Area (A) (ft ²)	Wetted perimeter (P) (ft)	Hydraulic radius (R) (ft)	Roughness coefficient (n)	Channel conveyance (K) (ft ³)
1	0.024	73	2.4	175	87	2.0	0.035	11,826
2	0.024	105	2.1	221	107	2.1	0.035	15,428
3	0.024	120	2.6	312	123	2.5	0.035	24,466

WHAT ARE THE PERCENTAGE CHANGES IN CHANNEL CONVEYANCES (ΔK) AND CHANNEL FLOW CAPACITIES (Q_{CAP}) FOR CROSS-SECTIONAL AREAS OF THE REACH CONTAINING THE DAMAGED BANK SITE?

The slope-area technique (adapted from Dalrymple and Benson 1976, French 1985) provides a simple method for estimating the channel flow capacity at damaged sites. The objective of applying this method is to estimate how cross-sectional areas, both before and after installing bank stabilization facilities, influence the effectiveness of the channel to transport flows. Cross-sectional data provide the necessary information for estimating the channel flow capacity at the damaged bank site. The method is based on a uniform flow concept that assumes the total cross-sectional area of the channel is effective in transporting flows. The method can be used where the change in channel conveyance in a reach does not exceed ~30%, the high-water marks are recognizable, and estimates can be made of boundary friction (e.g., where n is the Manning roughness coefficient).

Answer: Compute the percentage change in channel conveyances for cross-sectional areas of the reach (Table 1). The first step is to estimate the upstream (K_u) and downstream (K_d) conveyances of cross-sectional areas using equation 4:

$$K = \frac{1.49 R^{2/3}}{n} \quad (4)$$

where R is the hydraulic radius (ft), the ratio of cross-sectional area of flowing water to the wetted perimeter (A/P), and n is the Manning roughness coefficient (Table 1). The K_u and K_d values allow an estimate of the percentage change in channel conveyances.

Examples of the upstream (K_u) and downstream (K_d) conveyances for cross-sections on the North Fork of the Stillaguamish River (Table 1) indicate percentage change in channel conveyance (ΔK) of 23% for the upstream cross-sections 1 and 2 (15,428 -11,836 ft³/15,428 ft³) and 37% for downstream cross-sections 2 and 3 (24,466 -15,428 ft³ /24,466 ft³). The ΔK values of 23% and 37% indicate that the reach is not overly constrained or contracted downstream. These values suggest that the reach is a low-risk area for installing bank stabilization facilities. Higher-risk reaches for bank stabilization facilities can occur where ΔK values greatly exceed 30%.

The computation of the channel flow capacities (Q_{CAP}) for cross-sectional areas of the reach requires an estimate of the mean velocity ($\bar{\mu}$) for the cross-sectional areas (Table 2). The velocity depends on the slope and is inversely related to the boundary resistance or the Manning roughness coefficient (n). A common equation for expressing this relation is the Manning relationship (Dunn and Leopold 1978):

$$\bar{\mu} = \frac{1.49 R^{2/3} S^{1/2}}{n} \quad (5)$$

where R = the hydraulic radius,
 S = the slope of the water surface between cross-sections (the ratio of the change in water surface elevation to the length of the reach), and
 n = the Manning roughness coefficient.

Table 2. Example of cross-sectional estimates of channel flow capacities (Q_{cap}) for the North Fork of the Stillaguamish River at river mile 34 (Collings et al. 1973). Data for the downstream section 3 is from Collings 1973. The upstream sections 1 and 2 are approximations of cross-sectional areas (A_G). The value n represents an approximation of the total Manning roughness coefficient for the channel boundaries.

Cross-sections	Geometric mean area (A_G) (ft ²)	Geometric mean hydraulic radius (R_G) (ft)	Mean roughness coefficient (n)	Mean slope of water surface (S)	Mean velocity ($\bar{\mu}$) (ft/sec)	Channel flow capacity (Q_{cap}) (ft ³ /sec)
1 and 2	196.7	2.049	0.035	0.024	10.639	2,093
2 and 3	262.6	2.290	0.035	0.024	11.461	3,010

Roughness coefficients (n) increase as the boundary is rougher, causing increased friction. A summary of Manning roughness coefficient (n) for various channel and bank components (Table 3) is based on literature values (Cowan 1956, Chow 1959, Barnes 1967, French 1985, Sedell and Beschta 1991, Grant et al. 1992). Roughness coefficients vary with the different types of boundary surfaces: channel substrate (n_1), vegetation (n_2), cross-section variation (n_3), channel surface irregularity (n_4), obstructions (n_5), and the degree of channel meandering (n_6) (Table 3). The roughness coefficient for the degree of channel meandering (n_6) is estimated as follows (Cowan 1956):

$$n_6 = n' (n_1 + n_2 + n_3 + n_4 + n_5) \quad (6)$$

where n' is the adjustment factor. Roughness coefficients can also vary with channel depth (French 1985). Examples of n coefficients (Table 3) and estimates of total n values (Table 4) for natural river channels follow the Soil Conservation Service (SCS) method (Urquhart 1975).

The channel flow capacities (Q_{CAP}) for cross-sectional areas of the reach are estimated as follows:

$$Q_{CAP} = A_G \bar{\mu} \quad (7)$$

where Q_{CAP} = estimated discharge,
 A_G = the geometric mean of the cross-sectional areas, and
 $\bar{\mu}$ = the mean velocity (ft/sec).

Examples are provided of Q_{CAP} for cross-sections on the North Fork of the Stillaguamish River (Table 3). Q_{CAP} of 2,093 cfs for cross-sections 1 and 2, and 3,010 cfs for cross-sections 2 and 3, indicate that these flows are 31.7% and 45.6%, respectively, of the estimated bankfull discharge level (6,604 cfs). These flows indicate that the channel capacity of the measured cross-sections are within the bankfull discharge level and potentially suitable for the installation of a bank stabilization facility.

Table 3. Summary of Manning roughness coefficients (n) for channel and bank components and bank stabilization facilities.

Bank and channel components and conditions	Modifying (n) value		Comments	References (n)
	min	max		
1 Channel Substrate (n_1)				
Bedrock	0.025	0.030		Cowan 1956; Chow 1959
Sand	0.020	0.030	Diameter, 0.0025 to 0.08 in ^a	Cowan 1956; Chow 1959
Gravel	0.026	0.040	Diameter, 0.16 to 2.5 in ^a	Chow 1959
Cobble	0.030	0.050	Diameter, 2.5 to 10 in ^a	"
Boulders	0.040	0.070	Diameter, 10 to 80 in ^a	"
2 Vegetation (n_2)				
Low	0.005	0.010	short grasses, seedling tree switches (e.g., willows)	Cowan 1956; French 1975
Medium	0.010	0.025	medium turf grasses, weeds, tree seedlings to 2 years (no foliage), no channel bottom vegetation	"
High	0.025	0.050	tall turf grasses, willow 8–10 years (no foliage) or 1–2 years (full foliage), no significant bottom vegetation	"
Very High	0.050	0.100	tall grasses, mean flow is 1/2 height of grasses, full foliage willows, weeds on banks, bottom vegetation	"
3 Cross-section variation (n_3)				
Gradual	0.000		size and shape of channel cross-sections change gradually	Chow 1959; French 1975;
Alternating Occasionally	0.001	0.005	large and small cross-sections alternate occasionally, the main flow shifts from bank to bank	Grant et al. 1992
Alternating Frequently	0.010	0.015	large and small cross-sections alternate frequently, the main flow shifts frequently owing to changes in cross-sectional shape	"
4 Surface Irregularity (n_4)				
Smooth	0.000		compares to the smoothest channel attainable in a given bed material	Chow 1959; French 1975;
Minor	0.001	0.005	compares to carefully dredged channels, but having slightly eroded or scoured side slopes	Grant et al. 1992
Moderate	0.006	0.010	compares to dredged channels with moderate to considerable bed roughness and sloughed or eroded side slopes	"
Severe	0.011	0.020	badly sloughed or scalloped banks of natural streams, or badly eroded sides of channels, or unshaped, irregular surfaces of channels in rock.	"

Table 3—cont.

Bank and channel components and conditions	Modifying (n) value		Comments	References (n)
	min	max		
5 Obstructions (n_5)				
Boulders-Toe Rock	0.015	0.020	>24 in diameter angular rock ^b	Chow 1959; French 1975
Rip-Rap	0.010	0.015	3 to 30 in diameter angular rock ^b	"
Rock deflector	0.020	0.040	<24 in diameter angular rock ^b	"
Logs	0.010	0.040		
Root Wads	0.020	0.060	Root wads are more physically complex than log boles.	
Coir Geogrid	0.005	0.010	Modifying values are based on similarity to short turf and minor obstruction of cross-section after placement	Cowan 1956; Chow 1959
				∞
6 Degree of channel meandering (n_6)	n' adjustment factor ^c			
minor	0.00		Ratio of the channel length to valley length is 1.0–1.2.	French 1975
appreciable	0.15		Ratio of the channel length to valley length is 1.2–1.5.	"
severe	0.30		Ratio of the channel length to valley length is >1.5.	"

^aChannel substrate sizes after King County (1993).

^bRock sizes from King County (1993).

^c n' adjustment factor for estimating the roughness coefficients (n_c) for the degree of channel meandering where $n_c = n' (n_1 + n_2 + n_3 + n_4 + n_5)$, see text equation (6)

Table 4. Example of Manning roughness coefficients (n) for bank and channel components of a bank deflector facility and the total n value for an installed bank stabilization facility (e.g., Fig. 7): Log with root wad anchored by toe rock, with overlying coir wrap and brush layer in a moderately meandering channel. See Table 3 for definitions of roughness coefficients.

Step	Channel and bank components	Comment	Modifying (n) value
1	Channel substrate (n_1)	Basic channel n , gravel, cobble	0.030
2	Vegetation (n_2)	Low	0.010
3	Cross-sectional changes (n_3)	Alternating occasionally	0.005
4	Surface irregularity (n_4)	Moderate	0.008
5	Obstructions (n_5)	Toe rock	0.015
		Root wad	0.015
		Coir wrap	0.005
6	Degree of channel meandering (n_6)	Moderate	0.013
			Total $n = 0.101$

GUIDELINES FOR DESIGNING BANK STABILIZATION FACILITIES

WHAT IS THE OBJECTIVE OF THE BANK STABILIZATION FACILITY?

Determine the objective of the bank stabilization facility. For example:

- plant vegetation and install coir wrap and brush layer to prevent erosion of the banks;
- armor channel, plant vegetation, and install coir wrap and brush layer to prevent erosion of the banks;
- some combination of the above components with provisions for fish habitat cover; or
- some combination of the above components with lateral pool habitat created during construction.

BASELINE DESIGNS FOR THE BANK STABILIZATION FACILITY

The recommended FEMA guidelines provide for incorporating fish habitat components and refugia (e.g., fish refuge from high water velocities and predators) within bank stabilization facilities. Fish habitat components are defined for two habitat categories, *bank protection* and *bank cover*, designated by WDFW. The recommended *general* designs for facilities (Figs. 3–8) are baselines for the applicant’s development and refinement of specific sites. The baseline designs are *modified* from the King County’s “Guidelines for Bank Stabilization Projects” (Johnson and Stypula 1993). The general descriptions of the baseline designs are provided in Appendix A.

The baseline designs include:

Bank Protection Baseline Design

- Riprap with a toe key and live stake planting (Fig. 3).
- Riprap with a toe key, coir wrap and brush layer (Fig. 4).
- Deflector consisting of a log with root wad anchored below the ordinary high water (OHW) mark by toe rock. Overlying components include coir wrap and brush layer (Fig. 5).

- Rock deflector consisting of a large rock placed below the ordinary high water (OHW) mark by toe and key rock. Overlying components include coir wrap and brush layer. (Fig. 6).

Bank Cover Baseline Design

- Log with root wad cover anchored at the OHW mark by toe rock. Overlying components include coir wrap and brush layer (Fig. 7, Table 4).
- Lateral pool secured by bottom armor and toe rock. Cover provided by submerged log with root wad anchored by toe rock. Overlying components include coir wrap and brush layer (Fig. 8).

Project planning for the bank stabilization facility should begin the design process by using the baseline design alternatives (Figs. 3–8). The design process needs to be documented by providing answers to the following questions:

- What design features need to consider the flow duration? Methods for computing flow duration curves can be found in Dunn and Leopold (1978). The applicant should note whether the river is subject to flow regulation. If so, flow duration could be prolonged at various stages depending on water management programs. The analysis of flow durations allow the applicant to document the expected influences of flow regulation on the bank stabilization facilities.
- What are the sizes of substrate particles on the channel bottom that could be transported at the 2-, 5-, 20-, and 100-yr flood recurrence discharge rates? If bottom scour is expected to occur during peak flows, provisions need to be made to compute sediment rating curves (Bagnold 1980, US Army Corps of Engineers 1984, and US Environmental Protection Agency 1984) and scouring rates (Heiner 1991) (see Appendix C).

Sediment rating curves are also requested where the planned bank stabilization facility is to be installed in a sediment deposition province (Fig. 1). The sediment deposition province can be expected to offer fewer opportunities for including fish habitat components when installing bank stabilization facilities. Such low gradient provinces usually experience high deposition of fine sediments which can bury fish habitat components.

- What is the life expectancy of the bank stabilization project (refer to flood flow frequency analyses)?
- On which side of the channel on a meander bend is the bank site located (i.e., the convex or concave)?
- Do pool frequencies (pools/mile) and large woody debris frequencies (LWD/100 ft) in the channel indicate the design should incorporate large wood components into the bank stabilization facility?
- What fish species and life-history stages are expected to use the reach where the bank stabilization facility will be installed?

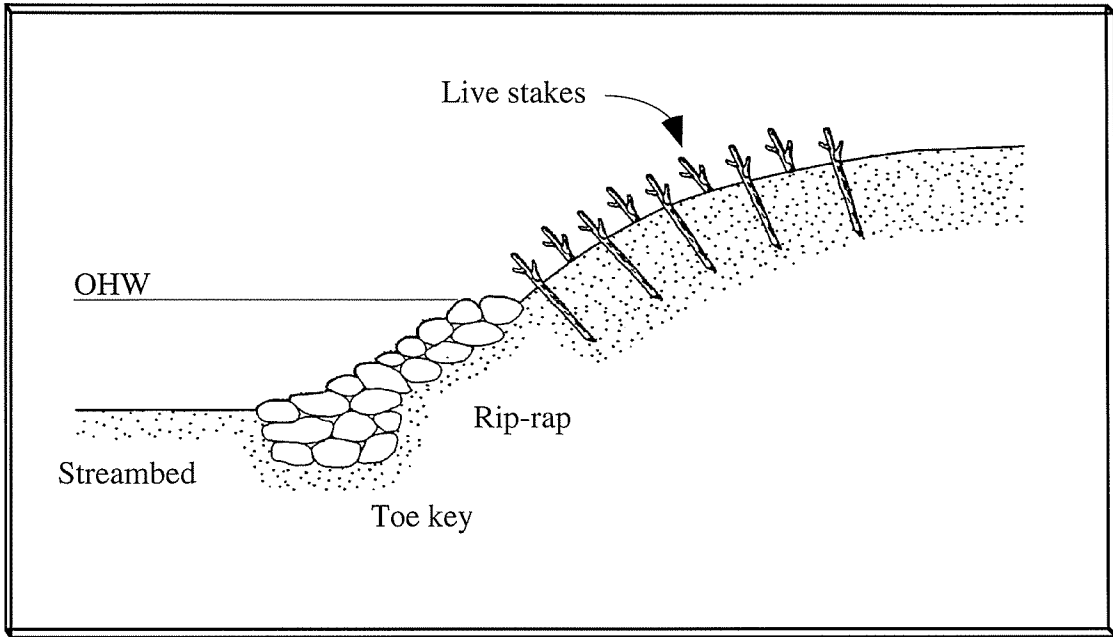


Figure 3. Riprap with a toe key and live stake planting.

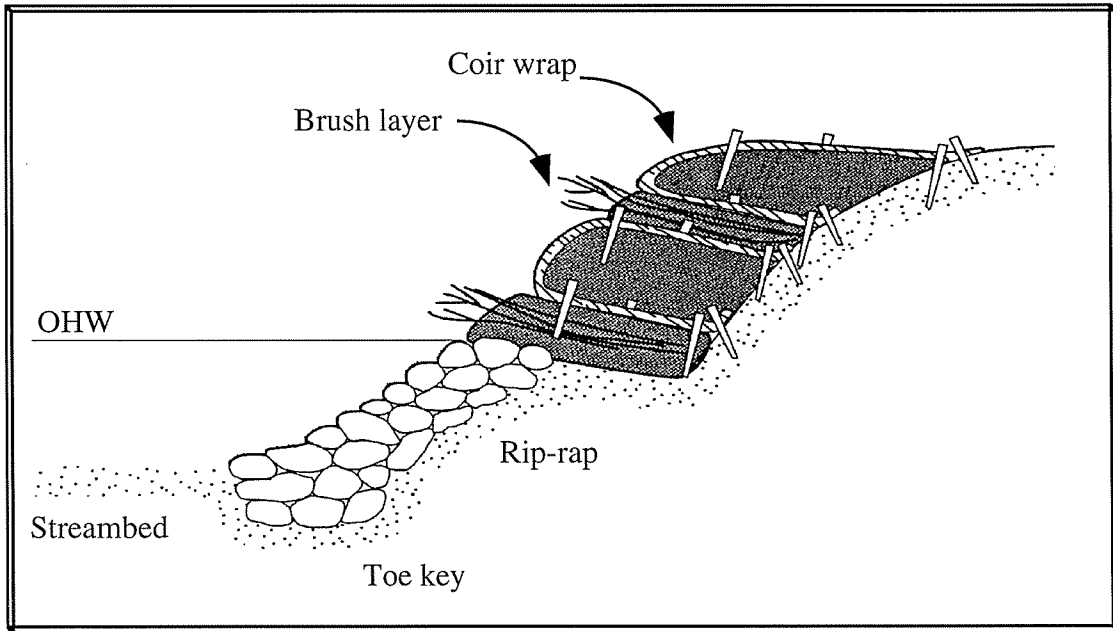


Figure 4. Riprap with a toe key, coir wrap and brush layer.

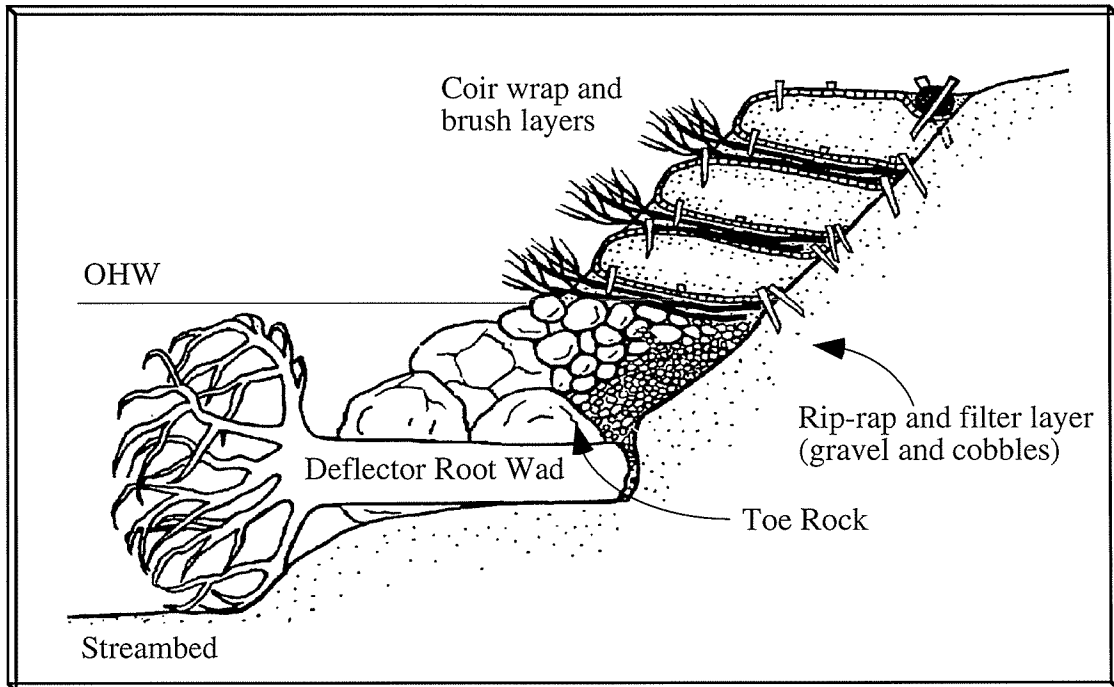


Figure 5. Deflector consisting of a log with root wad anchored below the ordinary high water (OHW) mark by toe rock. Overlying components include coir wrap and brush layer.

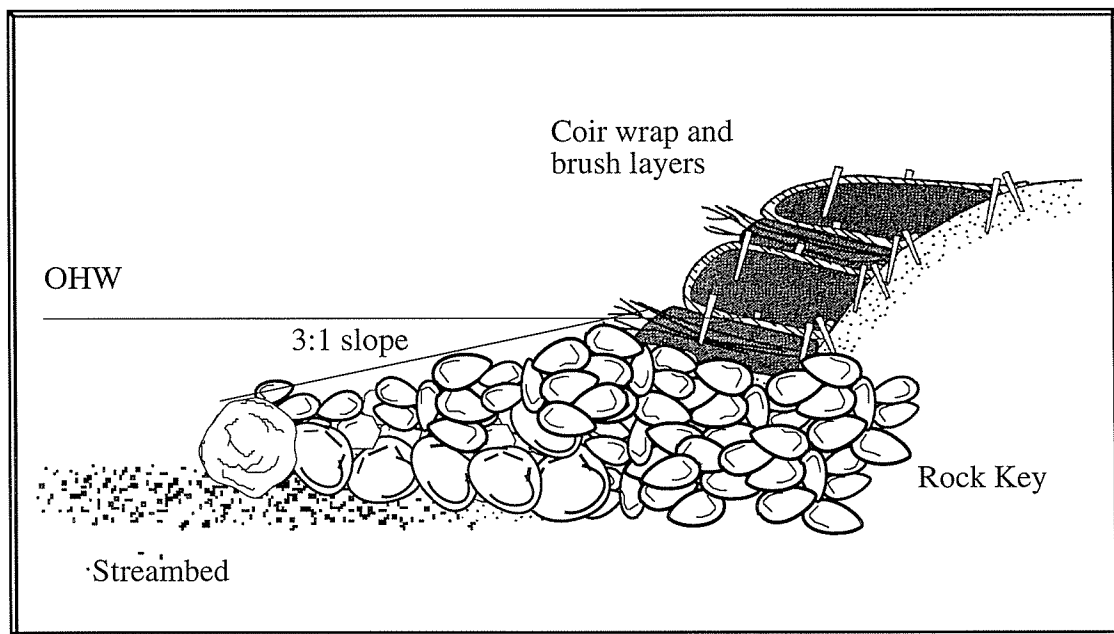


Figure 6. Rock deflector consisting of a large rock placed below the ordinary high water (OHW) mark by toe and key rock. Overlying components include coir wrap and brush layer.

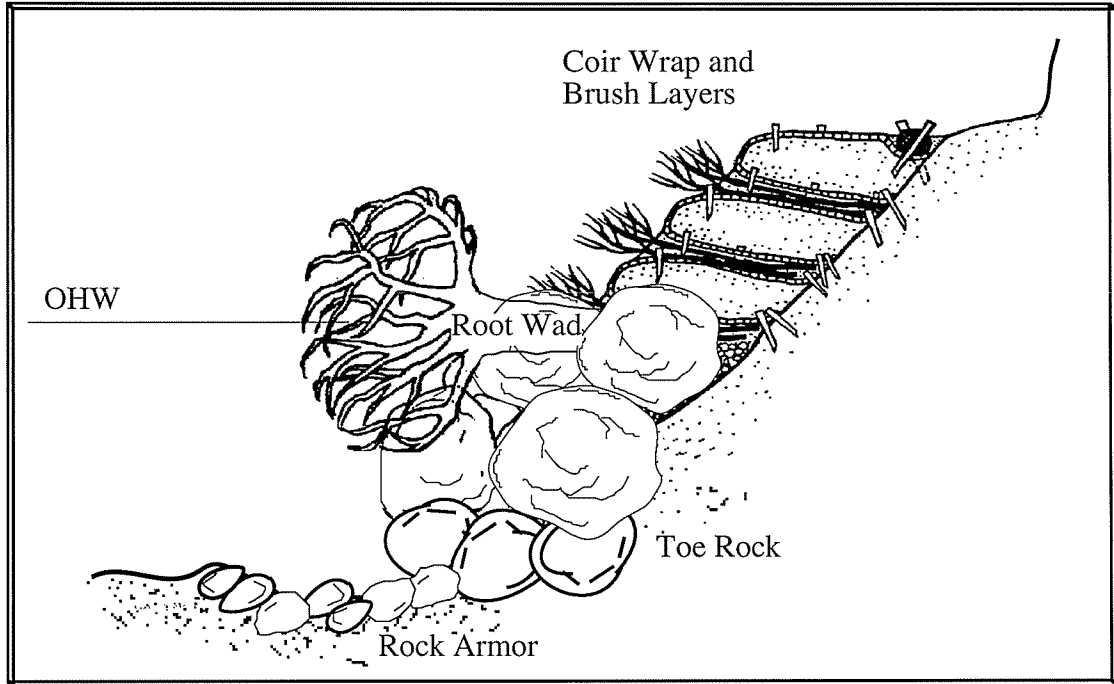


Figure 7. Log with root wad cover anchored at the OHW mark by toe rock. Overlying components include coir wrap and brush layer.

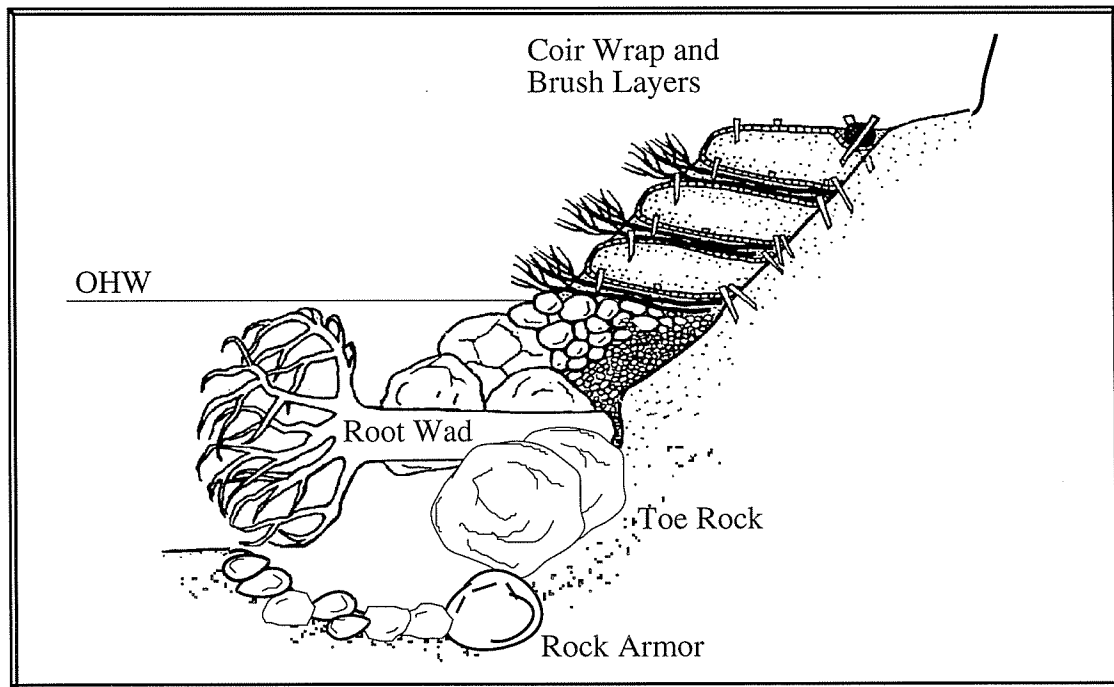


Figure 8. Lateral pool secured by bottom armor and toe rock. Cover provided by submerged log with root wad anchored by toe rock. Overlying components include coir wrap and brush layer.

GUIDELINES FOR DETERMINING THE EXPECTED RISK AND PERFORMANCE OF THE BANK STABILIZATION FACILITY

WHAT ARE THE CHANGES IN CHANNEL FLOW CAPACITIES (ΔQ) FOR CROSS-SECTIONAL AREAS OF THE REACH AFTER THE INSTALLATION OF A BANK STABILIZATION FACILITY?

Answer: The expected changes in channel flow capacities (Q_E) need to be estimated for cross-sections on the North Fork of the Stillaguamish River (Table 5) after the installation of a bank stabilization facility (e.g., Figure 7, Table 4). The channel flow capacities (Q_E) for the installed bank stabilization facility are 725 cfs and 1,043 cfs (estimated using eq. 7). These low flows reflect the increased total roughness coefficient (0.101) caused by the introduction of different boundary surfaces (Table 4). The changes in flows (ΔQ) after installing a bank stabilization facility are estimated by the following equation

$$\Delta Q = Q_{CAP} - Q_E \quad (8)$$

where Q_{CAP} is the initial channel flow capacity (Table 1) and Q_E is the flow capacity after the bank facility is installed. The ΔQ flows are 1,368 cfs (2,093–725 cfs) and 1,967 cfs (3,010–1043 cfs) or 65% of the initial Q_{CAP} flows. ΔQ flows >50% suggest that the applicant's project design should consider providing recommendations for compensatory flows within the reach.

DO PROVISIONS NEED TO BE MADE FOR COMPENSATORY FLOWS?

The compensatory flow (cfs equivalent to ΔQ) is the flow required to replace the loss in channel flow capacity caused by the installation of a bank stabilization facility. In general, a provision for compensatory flow is needed when the ΔQ is >10% of the discharge rate for the 100-yr flood recurrence interval.

Answer: Percent ΔQ s of 1,368 cfs and 1,967 cfs relative to the 100-yr flood recurrence discharge rate (27,859 cfs) for the potential bank stabilization facility (Fig. 7, Tables 1 and 5) at

Table 5. Example of cross-sectional estimates of change in channel flow capacities (ΔQ) for the North Fork of the Stillaguamish River at river mile 34 (Collings et al. 1973) after the installation of a bank stabilization facility. Data for the downstream section 3 is from Collings (1973). The upstream sections 1 and 2 are approximations of cross-sectional areas (A_G). The value n represents an approximation of the total Manning roughness coefficient for the channel boundaries.

Cross-sections	Geometric mean area (A_G) (ft ²)	Geometric mean hydraulic radius (R_G) (ft)	Mean roughness coefficient (n)	Mean slope of water surface (S)	Mean velocity (\bar{U}) (ft/sec)	Channel flow capacity (Q_E) (ft ³ /sec)	Change in channel flow capacity (ΔQ)
1 and 2	196.7	2.049	0.101	0.024	3.686	725	1,368
2 and 3	262.6	2.291	0.101	0.024	3.972	1,043	1,967

the North Fork of the Stillaguamish River reach are 4.9% and 7.1%, respectively. These percentages indicate there is no need to plan for a compensatory flow.

In situations where changes in channel flow capacities do exceed 10%, the applicant is required to recommend provisions for compensatory flow. For example, if the bank site is on a river subjected to flow regulation, the discharge for the 100-yr flood recurrence interval could be lower than historical discharge levels. An excellent example is the Green River in King County, Washington. The 100-yr flood discharge rate was reduced from 33,711 cfs to 12,838 cfs or 62% after the installation of the Howard Hanson Reservoir in 1962. In this situation, the compensatory flow would most likely exceed 10% of the 100-yr flood discharge rate.

A compensatory flow, in addition to reducing the risk of installing a bank stabilization facility, provides excellent opportunities for creating additional fish habitat. Compensatory flows, which give the channel greater flow alternatives during peak flows, can provide additional fish habitat by allowing habitat volumes to vary spatially during different seasons of the year. Such habitat opportunities could enhance fish survival during different life-cycle stages (e.g., rearing habitat for juveniles and spawning habitat for adult fish). Two common approaches for providing compensatory flows are to (1) allow overbank flow volumes by installing setback levees and (2) modify cutoff channels of meander bends and side channels to provide “release valves” for peak flow events.

The applicant should note that if they participate in the National Flood Insurance Program (National Flood Insurance Act of 1968, administered by FEMA), they will need to estimate compensatory flows in accordance to predetermined floodway and floodway fringe zones.

HOW WILL THE PERFORMANCE OF THE BANK STABILIZATION FACILITY BE MONITORED?

Answer: The performance guidelines for the bank stabilization facility can be determined by reviewing the applicant’s design process and answering the design questions. The applicant is requested to provide monitoring plans for a 10-yr period that establishes an annual monitoring program to assess the performance of the bank facility. Common methods including repeating cross-section surveys to determine channel adjustments (Schumm 1977, Dunn and Leopold 1978) and establishing “photo points” for repetitive photographs. Information about monitoring approaches can be found in MacDonald et al. (1991) and Wissmar (1993).

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APPENDIX A

The streambank stabilization guideline diagrams (Figs. 3–8) include general descriptions of streambank stabilization components and fish habitat components (FHCs). Bank stabilization below the ordinary high water (OHW) mark is achieved with the use of large toe rock, toe rock armor, and rock keys. Stabilization at and above the OHW mark is achieved with the use of root wads, riprap, coir wrap, brush layers, and live stake plantings. FHCs are defined for two habitat categories, *bank protection* (Figs. 3–6) and *bank cover* (Figs. 7 and 8) (M. Horn, Washington Dep. Fish & Wildlife, Olympia, pers. comm.), which are described below. Selected FHCs include submerged root wads and large rocks, and bank cover elements placed at or above the OHW line. Additional guidelines for bank stabilization projects can be found in Johnson and Stypula (1993).

RIPRAP WITH A TOE KEY AND LIVE STAKE PLANTING (FIGURE 3)

Riprap is typically placed below the OHW mark and is of a rock size and thickness appropriate to the stream segment in question (Johnson and Stypula 1993). At sites where toe erosion is prominent, riprap should be keyed into the streambed to a depth typical of estimated annual streambed scour. Toe keys can be constructed with rocks of >2-ft diameter, and the width of the toe key should be ~1.5 to 2 times the thickness of the riprap blanket. Riprap and toe keys are not considered fish habitat components (FHCs).

Live stakes are unrooted cuttings that are long and sturdy enough to be tamped into the ground above the OHW mark. Live stakes should be native species such as willow, poplar, and cottonwood.

RIPRAP WITH A TOE KEY, COIR WRAP AND BRUSH LAYER (FIGURE 4)

Riprap with a toe key can be placed as shown in Figure 3. Live stakes can be used above the OHW line in conjunction with coir wrap and brush layers. The natural fiber blanket (coir-cocconut fiber) is filled with soil, staked, and layered over horizontally placed live cuttings. Coir wrap is useful where banks cannot be sloped back or where erosive forces are strong. Coir wrap affords a level of stability intermediate to riprap or vegetative methods.

DEFLECTOR CONSISTING OF A LOG WITH ROOT WAD ANCHORED BELOW THE ORDINARY HIGH WATER (OHW) MARK BY TOE ROCK. OVERLYING COMPONENTS INCLUDE COIR WRAP AND BRUSH LAYER (FIGURE 5)

Bank protection is achieved with the use of toe rock, riprap and coir wrap. Here, a log with a root wad is secured within the toe key below the OHW mark. The root wad is a FHC and provides overhead cover as well as hydraulic complexity near the streambed. Where appropriate, this design acts as a deflector, directing flow away from the streambank. A scour pool may develop depending on the site objectives and design characteristics. This pool can provide valuable habitat for juvenile and adult fishes.

ROCK DEFLECTOR CONSISTING OF A LARGE ROCK PLACED BELOW THE ORDINARY HIGH WATER (OHW) MARK BY TOE AND KEY ROCK. OVERLYING COMPONENTS INCLUDE COIR WRAP AND BRUSH LAYER (FIGURE 6)

Rock deflectors consist of 3-5 rows of angular cut rock and boulders extending into the channel at an upstream, downstream, or perpendicular angle from the streambank. Stream size, gradient, bank height, expected flood height, and channel configuration all play a part in deflector site design and appropriateness. Deflectors can promote both pool formation and sediment deposition in reduced-velocity back-eddies. Additional design characteristics can be estimated from Heiner (1991) and Johnson and Stypula (1993).

LOG WITH ROOT WAD COVER ANCHORED AT THE OHW MARK BY TOE ROCK. OVERLYING COMPONENTS INCLUDE COIR WRAP AND BRUSH LAYER (FIGURE 7)

The streambank is protected by a combination of elements below and above the OHW mark. A toe key with large boulders is placed on the bank to the depth of annual streambed scour. Large boulders anchor and support bank-placed root wads at the OHW mark and both bank-placed elements provide bank cover for fishes. Root wads with a log (>10 ft in length) can be embedded in the streambank. The root wad dramatically increases overhead cover complexity. Above the OHW line, coir wrap is placed to provide bank stabilization and promote vegetative growth.

LATERAL POOL SECURED BY BOTTOM ARMOR AND TOE ROCK. COVER PROVIDED BY SUBMERGED LOG WITH ROOT WAD ANCHORED BY TOE ROCK. OVERLYING COMPONENTS INCLUDE COIR WRAP AND BRUSH LAYER (FIGURE 8)

Bank protection is achieved with the use of toe rock, toe rock armor, riprap and coir wrap. Toe rock armor is used to fix in place a pool beneath a submerged bank placed root wad, both of which, secondarily to stabilization, are fish habitat components. Toe rock keyed into the streambank, and overlying boulders, secure the log with the root wad in place beneath the OHW mark. Bank-placed boulders and root wads can dramatically increase hydraulic complexity and flow resistance, modifying flow characteristics nearest to the streambank and directing water flow away from the streambank.

APPENDIX B

Sediment rating curves are required when the planned bank stabilization facility is to be installed in geomorphic provinces that experience high erosion and sediment deposition rates. The changes in sediment transport and stream power relationships (e.g., rating curves) can be assessed using the sediment transport models (Bagnold 1980), discharge rates generated by the HSPF model (US Environmental Protection Agency 1984), and water surface elevations and other hydraulic parameters for river reaches using the HEC-2 model (US Army Corps of Engineers 1984). These activities involve surveying cross-sections and coding the information into the HEC-2 model. The Bagnold equations are as follows:

$$I_b = 0.1[(\omega - \omega_o/0.5)^{1.5}(d/0.1)]^{-2/3}(D_{50}/0.0011)^{-0.5} \quad (1)$$

where ω = the stream power,

$$\omega = (\rho QS / \text{width}) = \tau u' = \rho Y S u' \quad (2)$$

and ω_o = the critical stream power for bed motion,

$$\omega_o = 290(D_{50})^{1.5} \log[12d/D_{50}] \quad (3)$$

and where ρ = the absolute density mass per unit volume,

Q = the discharge,

S = gravity or channel gradient,

τ = the mean boundary shear stress,

u' = the mean flow velocity, and

Y = the flow depth

APPENDIX C: GLOSSARY

- Bank cover:** Anything that provides protection for fish or wildlife, or both, from predators or ameliorates adverse conditions of stream flow and seasonal changes in metabolic costs. May be instream or overhead structures such as large woody debris (root wads), boulders, or vegetation placed at or above the OHW line (Johnson and Stypula 1993).
- Bank deflector:** A structure (rock or wood) that is attached to one bank and projects into the flow, directing flow toward the middle of the channel and away from erodible banks.
- Bankfull discharge:** The discharge corresponding to the stage at which the natural channel is full. This flow has a recurrence interval of 1.5 to 4 yr depending on the channel gradient and bank materials.
- Boulder:** Sediment particles having a diameter >256 mm (10 in).
- Channel conveyance (K):** The effectiveness of the channel reach to transport flows as determined by specified cross-sectional data prior to installing a bank stabilization facility.
- Channel flow capacities (Q_{CAP}):** The effectiveness of the channel to provide a discharge rate (cfs) as determined by specified cross-sectional data prior to installing a bank stabilization facility.
- Cobble:** Sediment particles larger than pebbles and smaller than boulders, usually 64-256 mm (3 to 8 in) in diameter.
- Coir:** A woven mat consisting of coconut fibers used for streambank stabilization purposes. The mat is used for construction of coir wrap to prevent further erosion of the natural streambank (Johnson and Stypula 1993).
- Filter:** A layer of fabric, sand, gravel, or graded rock used between the bank revetment or channel lining and soil. Also called a filter layer or filter blanket (Johnson and Stypula 1993).
- Fish habitat components (FHC):** A structure that is placed at the toe of the armored section and on the bank to break up velocities and provide rest/hiding areas for fish. These structures typically are made up of large boulders, large woody debris (LWD), such as trees with root wads, or a combination of rock and LWD. Often deflectors can be considered FHCs, depending on design and location (M. Horn, Washington Dep. Fish & Wildlife, Olympia, pers. comm.).
- Flood recurrence interval:** This describes the time interval (years) between which floods of a given discharge (cfs) occur and are river-specific (Dunne and Leopold 1978).
- Gravel:** Sediment particles larger than sand and ranging from 2 to 64 mm (0.25 to 3 in) in diameter.
- Live stakes:** Live, woody plant cuttings, capable of rooting, that are taken from native trees and shrubs (Johnson and Stypula 1993).
- Manning roughness element:** Any obstacles on the streambank or in the channel that deflects flow and changes its velocity, including bank-placed facilities.
- Manning's roughness coefficient (n):** This coefficient describes the resistance to flow in a given channel and is a dimensionless variable used in calculating water velocity and stream discharge. n is highly variable and largely dependent on channel cross-section surface roughness, vegetation, channel irregularity, degree of channel meandering, obstructions, silting and scouring, and channel depth (Chow 1959).
- Ordinary high water (OHW) mark:** The mark along a streambank where the waters are common and usual. This mark is approximately at the margin of the active channel, above which is the lower riparian limit, and below which vegetation may be absent or differ markedly from growth above the OHW mark (Johnson and Stypula 1993).

Riprap: A layer, facing, or protective mound of stones placed to prevent erosion, scour, or sloughing of a structure or embankment. Also refers to the stone used (Johnson and Stypula 1993).

Root wad: Also known as large woody debris (LWD), root wads are generally tree boles (e.g., logs) with the root ball attached, that intrudes, embeds, or is placed in the streambank as a FHC.

Sand: Mineral particles ranging from 0.0625 to 2 mm (0.0025 to 0.08 in) in diameter.

Toe: The break in slope at the foot of a streambank where the bank meets the bed (Johnson and Stypula 1993).

Toe rock key: Large rock, usually >2 ft in diameter, that is dug into the streambed at the toe to a depth approximate to the annual streambed scour depth. A toe key prevents further toe erosion (Johnson and Stypula 1993).

Toe rock: Large rock, placed on the toe of the bank within the zone of highest flow velocity, to prevent streambank erosion and provide flow refuges for fishes (Johnson and Stypula 1993).