Chapter 6

Techniques

This chapter provides information on specific techniques used in integrated streambank protection.

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Groins

Flow-Redirection Techniques

DESCRIPTION

Groins, also called spur dikes, are large roughness elements that project into the channel from the bank and extend above the high-flow, water-surface elevation. They are usually constructed in a series and act together hydraulically to provide continuous bankline roughness. Though commonly constructed of rock, groins can be built with large woody debris or pilings that collect debris. *Figure 6-1* (at the end of this technique discussion) shows various applications of groins throughout Washington State.

The main functions of groins are to redirect flow away from a streambank and to reduce flow velocities near the bank, which, in turn, encourages sediment deposition. As more sediment is deposited behind the groins, banks are further protected. Groins tend to induce scour near their tips, and scour holes are likely to form in those locations. Depending upon factors such as the angle of attack of flood flows and depositional patterns, eddies may form between groins, which may lead to scour along the bases of groins or adjacent streambanks. In general, however, deposition can be expected between groins that are properly designed and installed in an appropriate location.

Barbs and groins are often mistaken for one another because they look similar, and both function to redirect flow. The primary difference between groins and barbs is that groins are higher-profile structures that tend to deepen the thalweg and narrow the stream, while barbs have less of an effect on the cross-sectional shape of the stream.

APPLICATION

Groins are used to realign a channel or redirect flow away from a streambank to protect it from erosional forces. They are also used to increase channel roughness at locations that lack roughness elements. Groins are best applied as bank protection in long, uniform bends where the upstream flow approach remains relatively constant over time. Frequently, groins are applied to reduce flow velocities and shear stress along eroding banks. In certain cases, groins can be used to narrow the channel in low-gradient, aggrading reaches causing flow velocities and sediment transport rates to increase.

Prior to applying groins as a bank-protection technique, it is important to understand the existing physical characteristics and geomorphic processes present in a potential project reach (see Chapter 2, *Site Assessment* and Chapter 3, *Reach Assessment* for guidance). Groins work best in wide-radius bends where they can even out the hydraulic effect along the bank. In tight-radius bends or other constricted reaches, groins may not be very effective, and their application can further exacerbate existing erosion problems or move them upstream. Care in sizing and spacing the groins is crucial to avoid creating a constriction. Use of groins within a channel migration zone is also not recommended because it interrupts the natural riverine channel-migration process and may cause future erosion problems upstream and downstream. Refer to the screening matrices in Chapter 5, *Identify and Select Solutions* for more guidance on the applicability of groins based on the mechanism of failure and causes of streambank erosion.

Groins are often installed as a combination of habitat enhancement and bank protection. However, recent work has called into question the use of rock structures for habitat enhancement and, therefore, as mitigation. Density at rock groins were less than those found at adjacent, untreated banks.[1]

Variations

Groins can be set back from the active channel as an eventual line of bank protection. This type of groin is referred to as a *buried groin*. Buried groins are discussed as a separate technique in this chapter.

Groins can be constructed to be permeable or impermeable. An impermeable groin (e.g., solid-rock groin) allows minimal flow-through, whereas a permeable groin (e.g., log groin) allows flow to pass through it easily. A permeable groin acts as sieve and tends to collected a greater amount of woody material than an impermeable groin. As material is collected at the permeable groin, it eventually functions more like an impermeable groin. Impermeable groins tend to be more effective at redirecting the flow than permeable groins with no accumulated debris.

Tight-Radius Scour Holes

As mentioned earlier, groins are not particularly effective in tight-radius bends. Indeed, they can do more harm than good. A tight-radius bend with a deep scour pool acts as an energy sink, significantly dissipating stream energy. Partially filling the bend and pool with groins and/or shortening the flow path through the bend will increase the energy leaving the site, possibly increasing erosive forces where they were minimal before. For this reason, it is best to avoid using groins in tight-radius bends and pools. Again, groins work best in wide-radius bends where they can even out the hydraulic effect along the bank.

High-Gradient Channels

In higher-gradient channels, groins tend to act more like jetties. Under these conditions, they are more effective at diverting or redirecting flow than at increasing roughness.

Emergency

Groins have been used successfully during emergency situations for bank protection. Groins are constructed by dumping or placing rock from the top of the bank. This type of emergency installation can be carried out during flood events or immediately after flood waters have receded. Groins constructed under flood conditions will necessarily be short, only extending from the bank as far as can be reached by equipment on the bank. Typically, groins installed under emergency conditions will require further construction after floodwaters recede to ensure they are adequately keyed into the bank and constructed to the proper dimensions for their intended, long-term function. Once the crisis has passed, groins constructed during an emergency may need to be replaced with a bank-protection technique that better addresses the mechanism and causes of erosion.

EFFECTS

Groins constrict the channel by creating roughness and by blocking a portion of the channel. The constriction can increase erosive shear stress on the opposite bank. Caution is advised when designing groins that are more than 10 percent of the bankfull channel width, particularly in channels that are already constricted. A constriction creates a backwater effect (increases the water depth) upstream, decreasing flow velocities and increasing sediment deposition. A tailout bar often forms downstream of a constriction as the channel expands and loses transport capacity. Once a tailout bar is formed, moderate flows may pass around the bar and along channel banks, causing toe erosion.

The intended effect of groins is to shift the thalweg away from the bank. The new thalweg alignment may affect the downstream channel or banks. Appropriate spacing and sizing of groins to dissipate flood-flow energy can minimize this effect. Energy dissipation at a groin typically creates a scour hole in the channel bed near the tip of the groin. Rock or other materials used to construct a groin can be placed below the estimated scour depth at the groin tip to prevent undermining. Excess rock can also be placed on the channel bed such that, as scour occurs, it launches into the scour hole. Scour holes provide important cover and holding habitat for fish. See Appendix E, *Hydraulics* to learn about methods used to calculate scour depth. Sources of additional information regarding the effects of groins can be found at the end of this technique discussion.[2,3]

DESIGN

The design of groins for bank protection requires balancing the effects of creating a constriction, providing channel roughness, generating habitat benefits and controlling costs. If groins must be used at sites where they will not be as effective as they could be, their impacts can be at least partially mitigated by building them shorter and closer together than typically applied.

The Federal Highway Administration has developed a well-established design process for traditional, impervious rock groins, which can be found in FHWA Publications HEC-20 and HEC-23.[4,5] Conceptual design drawings are shown in *Figure 6-2* and *Figure 6-3*.

Orientation

Groins may be aligned perpendicular (standard) or angled upstream or downstream to the flow. Regardless of orientation, groins should always be oriented relative to the high-flow streamline in order to function correctly. The high-flow streamline may not correspond with the low-flow channel alignment, particularly in braided channels.

An upstream-orientation bank angle generally creates the greatest roughness and flow disturbance and results in the greatest scour depth at the groin tip. Should the groins be overtopped, an upstream orientation may result in less bank erosion than a downstream one.

Downstream, angled groins tend to create less roughness and are recommended for use in high-gradient channels or degrading reaches where flow redirection is more important than increasing channel roughness. With less roughness, scour-hole development is minimized along the channel bank between the groins. This orientation may cause more flow to impinge on the opposite bank. If downstream angled groins are overtopped, the cresting flow will impinge directly on the adjacent, downstream bank. Downstream-oriented groins are often used for navigation channels because less turbulence is created, and flow patterns are more uniform.

Length

Groin length is defined as the projected length of the groin perpendicular to the flow direction. The optimal design length of a groin depends upon the location and objectives of the project and varies according to channel width and spacing among groins. The longer the groin, the greater length of bank it will protect. Length is usually limited by the degree the channel is confined and the opposite bank's susceptibility to erosion. As a groin is lengthened, the channel becomes more constricted. This produces upstream backwater, a deepened and narrowed channel off the tip of the groin, an increase in the flow directed across the channel and increased stream energy downstream. Flume tests indicate that diminishing returns are gained from groin lengths greater than 20 percent of bankfull channel width.[4] Impermeable groins are typically limited to 15 percent of the bankfull channel width.[3] Depending upon site-specific hydraulics and upstream and downstream effects of roughening and constricting the channel, groins may need to be more closely spaced and shorter in length than normal to reduce off-site impacts.

Spacing

Spacing between groins depends upon project objectives and is a function of groin length, angle, permeability and the channel radius of curvature. Although not specifically determined for groins, the spacing of experimental baffles (which function hydraulically similar to groins) was found to have an influence on roughness in flume studies. Groins that are spaced too close to each other or too far from each other create less roughness than optimally spaced groins. Groins that are spaced too close to each other tend to mimic a riprap bank; there is minimal space between groins for turbulence and energy dissipation to occur. When groins are unnecessarily close to each other, they are more costly, and they require greater bank disturbance during construction. For increased habitat and diversity, wider spacing is desired. Groins installed in tight-radius curves must be positioned closer to each other than normal; all the more reason to avoid placement of groins in such circumstances.

Spacing between groins is influenced by the length of the groin and the ratios of groin length to channel width and channel radius of curvature to channel width.[6] Maximum spacing is determined by the intersection of the tangent flow line with the bankline, assuming a simple curve. This maximum-spacing approach is not recommended, but can be used as a reference for designers. In situations where some erosion between groins can be tolerated, the spacing can be set somewhere between the recommended distance and the maximum. Longer groins can be placed further apart from each other than shorter ones.

Flume studies show that stream flow expands out of the channel constriction created by a groin at an angle of about 17 degrees (this value is for impermeable groins; the angle varies for permeable groins and they should be specifically designed depending on their permeability).[4] The next downstream groin is placed at the point where the flow line would intersect the bank if there were not a downstream groin. This is roughly 3.3 times (tan 73 degrees) the length of the groin from the point of contact with the bank and its tip. Groins have been successfully placed at distances of about two to five times their length, which adds a range to the previous result and allows some flexibility in locating them. By using a tangent to the high-flow line, one can project a line off the tip of a groin and identify on the bank the approximate location of the next groin.

Height

The height of groins should not exceed the bank height because erosion in the overbank area could increase the probability of out flanking at high stream stages. If flood flows are below the top of the bank, the groins can be lower. The groin crest should slope down and away from the bank. This is usually preferred since it creates less channel confinement at high flows. Additionally, because bank shear generally decreases with elevation, groin elevation may not need to extend the full height of the bank.

Key

To ensure that groins are not flanked by high flows, they must be properly keyed into the bank. The length of this key varies with the installation. A minimum key of eight feet or $4(D_{100})$, whichever is greater, has been proposed by The Natural Resources Conservation Service.[7] On large rivers, this is insufficient. Exactly how much is enough will depend upon the erodibility of the soils and other site-specific details. The upstream groin should be keyed in at least 50 percent of its exposed length. This groin acts as the keystone to the rest of the group. If it fails, others may fail. In a large group of groins, perhaps every fifth should be keyed in at a greater depth than the others, in case there are failures within the group. The length of key should be equal to or greater than 1.5 times the bank height.[5] Equations have been developed for estimating key length based on the expansion angle and radius of curvature[6]:

When the radius of curvature is large (R > 5(W)) and the spacing is greater than L/tan(Ø), then:

$$LK = S \tan(Ø) - L$$

When the radius of curvature is small (R<5W) and the spacing is less than tan(Ø), then:

$$LK = L/2(W/L)^{0.3}(S/R)^{0.5}$$

Where:

R = radius of curvature
W = channel width
S = spacing between groins
L = length of groin measured from the groin tip to the bankline
Ø = angle of expansion = 20º
LK = length of key

Groins should also be keyed into the channel bed or constructed with a launchable toe to protect against scour. The key should extend into the streambed to the predicted scour depth at a minimum. Alternatively, rock added to the tip of the groin can protect against scour by gradually launching and falling into the scour hole as it develops. This eliminates the need to dig in the bed of the channel, and it places the toe at the correct depth of scour. Estimates for the required amount of extra rock can be based on scour-depth calculations.[3] Launching is most often used on channels with fine-grained beds. It has been used inappropriately on beds that do not scour, resulting in excess rock in the channel. This extra, launchable rock narrows the channel and reduces habitat value.

Wooden groins are generally supported by piles driven into the river bed. The depth of pile penetration required should be determined by a geotechnical engineer. Piles should be driven to a depth adequate to resist hydraulic forces, floating-debris impacts and buoyant forces at the design discharge, assuming maximum scour is attained. This depth will vary according to site hydraulics, expected impact from floating debris and subsurface materials. Stone can be placed along the base of a wooden groin to counter scour that might otherwise destabilize the structure.

Permeability

The effective application of permeable groins depends upon stream characteristics, the desired reduction in flow velocity and the radius of curvature. Permeable groins can be used successfully in mild bends and where only small reductions in velocity are desired. In stream systems where woody materials exist, permeable groins collect and retain floating, woody material and, over time, become less permeable. Impermeable rock groins are by far the most commonly used in Washington streams. Suitable rock size can be determined by a number of methods.

Permeable groins can be made from a variety of materials. Wood pilings, large woody debris, a combination of rocks and logs, and/or concrete doloes have all been successfully used. The greater the stream energy, the more robust the materials and their anchoring must be.

Material Sizing

If a hydraulic analysis of the site has been performed, the velocity will be known, and the Isbash relationship can be used to size the rock.[3] This equation was derived for bridge abutments and has been used successfully for some time. The Natural Resources Conservation Service and the U. S. Army Corps of Engineers both have developed riprap sizing methods. The conservation service recommends using a D_{50} equal to 1.5 to two times the size determined from riprap design for bankfull flow.

Rock should be angular, and not more than 30 percent should have a length exceeding 2.5 times its thickness. Rock should be well-graded, with only a limited amount of material less than half the median rock size. The size of rock can be determined by available riprap design procedures. Rock sized for typical bank revetment riprap is too small for groins. The NRCS recommends using a D_{50} rock size that is two times the D_{50} rock diameter determined using standard riprap design procedures for continuous riprap at bankfull conditions. Large woody debris installed in groins should be at partially submerged for habitat value and longevity. Refer to Appendix I, *Anchoring and Placement of Large Woody Debris* for guidance.

Log groins are typically constructed using wooden or steel piles, wood cross-logs and rootwads. Steel piles have the advantage of being stronger, allowing better (deeper) penetration through gravel or cobble subsurface materials; and they are free of buoyant forces. The obvious disadvantage to steel piles is their longevity - they are likely to far outlive the other components of the groin. Cross-logs are typically branchless logs cabled across the piles to form a fence-like structure. Rootwads can be included in the structure to add complexity. See Appendix I for additional information.

BIOLOGICAL CONSIDERATIONS

Mitigation Requirements for the Technique

Groins redirect flow away from an eroding bank and prevent further, lateral, channel migration. Periodic inputs of gravel and woody debris, resulting from bank erosion, will be reduced, representing a lost opportunity for future development of habitat complexity. Woody debris can be incorporated into the construction of groins as one means of mitigating for habitat loss. Groins may also capture floating wood debris, especially if the surface is left jagged rather than smooth.

Thalweg alignment is often affected by placement of groins. A relocated thalweg will dictate new erosional and depositional patterns in the channel, which may impact existing spawning areas. The use of groins to provide bank stabilization along an eroding channel bend will reduce near-bank pool habitat. Relocation of the thalweg away from the bank results in reduced riparian function and overhead cover from existing vegetation on the bank. Live, woody plant cuttings can be incorporated into groin construction as mitigation for loss of bank vegetation. Segments of bank located between groins can also be revegetated, with both woody and herbaceous species to replace lost riparian function.

Refer to Chapter 4, *Considerations for a Solution* for further discussion of mitigation requirements and to Matrix 3 in Chapter 5 for more detail on mitigation needs for this bank treatment.

Mitigation Benefits Provided by the Technique

A groin will provide some fish habitat at all flows. Cover habitat can be provided in the surface turbulence created by a groin. At lower flows, slack-water habitat may be formed on the downstream side of the groin. A back eddy often forms off the tip of each groin, a good feeding station for fish in the slower water. At higher flows, the back eddies can become fairly strong and have high energy. A groin may provide some refuge from flood flows, or the swirling eddies may become too great for fish to hold in. If the rock used to construct the groin is large enough, it may provide interstitial cover for fish, unless the rocks have been over compacted to interlock.

Groins may accrete gravel and other sediment, either at a single groin or, more likely, between groins in a series. This accretion may raise the riverbed and provide shallow, slack-water habitat along the accreted shoreline. The upstream accretion may sort gravels and create a spawning area where none existed before. Accretion may increase to the point where a beach forms that remains unsubmerged during all but high-water events. Slack-water habitat at extreme flows may provide refuge for both adults and juveniles.

Refer to Matrix 3 in Chapter 5 for more detail on mitigation benefits provided by this bank treatment.

RISK

Habitat

Spawning areas can be impacted by the construction of groins, particularly if the habitat is located on the margin of a point bar, in the tailout of a bank scour pool or on the riverside of the thalweg on a straight river stretch. As discussed in the section on general fish-habitat needs, scour can kill eggs or alevins that are still in the gravel. Over the long term, the bed and bars should stabilize, and these scour impacts should become minor.

In a situation where the existing unarmored bank may be sustaining a deep, lateral, scour pool with overhanging vegetative cover and woody debris, the placement of groins will likely eliminate this habitat. The habitat-generating value of the groins will likely not compensate for elimination of the better habitat. In these cases, the best habitat decision is to leave the eroding bank alone and build no groins.

A survey of over 600 bank-stabilization projects in western Washington assessed five different types of bank treatments for their impacts/benefits to fish.[1] Rock groins alone and with large woody debris were two of the treatments evaluated. Stabilized sites were compared with untreated control sites in the same river that were naturally stable and as similar to the stabilized site as possible. Bank treatments that incorporated large woody debris were the only types that consistently had greater fish densities than their corresponding control areas during spring, summer and winter. Fish densities were generally lower at groins than their controls during the spring and summer, but greater during the winter.

In general, the study results suggest that fish densities are generally lower at banks stabilized with groins except those with a large woody debris component. Fish densities were positively correlated with total surface area of large woody debris at all sites. Based on these results, such debris should be incorporated into groins whenever practical. Most large woody debris used in surveyed groin projects was found between the groins (a depositional area). These areas often lacked sufficient depth for rearing habitat. Additionally, large woody debris incorporated directly into the groins was often placed too high with respect to summer water depths. Care should be exercised when incorporating large woody debris into groins to make sure that it is placed at the correct elevation within the groin.

Infrastructure

Avoid existing vegetation as much as possible, positioning the groin between trees rather than removing trees and brush. Minimize bank sloping and armoring between the groins. If the bank between groins is unvegetated or newly armored, revegetation should be initiated on both the slope and on the top of bank.

Reliability/Uncertainty of Technique

The use of groins is a well-established and reliable method of realigning a channel thalweg when standard design and construction approaches are applied.

Recent studies have questioned the use of rock structures as habitat. Fish appear to prefer pool habitat along untreated banks over that provided by rock groins. Therefore, rock groins should not be used strictly as habitat features.

CONSTRUCTION CONSIDERATIONS

Materials Required

Groins may be constructed with a variety of materials. Angular rock is the most common type of material used; however, large woody debris and concrete doloes have also been used.

Woody vegetation should be planted in all groin surfaces that have the proper hydrologic zones and growing medium. Generally, live cuttings are the most suitable. Refer to Appendix H, *Planting Considerations and Erosion-Control Fabrics* for more information.

Timing Considerations

Groins are best constructed during low flow, when dewatering is possible and when critical life stages of resident and anadromous fish are less likely to be impacted by construction activities. In order to install rock or logs to the depth of scour, excavation within the channel bed will be necessary and, consequently, will require temporary dewatering systems. Keying into the streambed by constructing a launched toe may also require dewatering. Dewatering allows for ease of installation and limits siltation of the stream during construction. This can be accomplished with a coffer dam during low water.

Critical periods in salmonid life cycles, such as spawning or migration, should be avoided. Instream work windows vary among fish species and streams. Contact the Washington Department of Fish and Wildlife's Area Habitat Biologist for information on work windows (see Appendix B, *Washington Department of Fish and Wildlife Contact Information*). Further discussion of construction timing and dewatering can also be found in Appendix M, *Construction Considerations.*

COST

The main function of groins is to redirect flow away from the bank, thus modifying flow patterns in the near-bank region, encouraging sediment deposition and reducing bank erosion. Corresponding decreases in velocities and shear stresses along the bank allow less-intensive and less-expensive bank treatments to be applied between groins. In other words, groins, in combination with other bank treatments, may not only protect a streambank more effectively than traditional bank-revetment measures, they may cost less as well.

The major cost components of groin construction include access, materials, dewatering and installation. For further information on the costs of these components and specific construction materials, refer to Appendix L, *Cost of Techniques*. Cost of individual groins may vary from $2,000 to $5,000 depending upon their size and site-specific factors.

MAINTENANCE

Maintenance of groins may include replacement of construction materials (e.g., rock, logs) that shift or are removed by high flows. This may include replacement of nonsurviving plant material. Groin materials lost to high flows should be replaced before damage occurs to the bank or structures located between the groins.

Erosion along the perimeter of the groin, as well as along the streambank between groins, should be closely monitored and evaluated for need of repair. Rock should be placed along the bank for a short distance upstream and downstream of the groin tie-in point to the bank. Placement of this material will help to prevent erosion at this critical location, which could result in flanking of the groin at high flows.

MONITORING

Because groins involve impacts to the channel and banks, they will require comprehensive monitoring of the integrity of the structures, channel and bank features and in-channel habitat. Monitoring of groin projects should be initiated prior to construction, with baseline-conditions surveys of the physical channel, its banks and its habitat value. This should include five cross sections at intervals equal to the channel width upstream, five downstream and one through each groin at a minimum. This will allow comparison of modified conditions to preproject conditions. Additionally, monitoring should include detailed as-built surveying and photo documentation from fixed photo points of the project area and upstream and downstream reaches to allow for evaluation of performance relative to design. Details on development of a monitoring plan are discussed in Appendix J, *Monitoring*.

Monitoring of groin structures should include preproject and subsequent annual surveys of key members, as well as visual assessments of groin configuration, dimensions and hydraulic function. The general integrity of the structures should be evaluated, including the identification of any significant settling of header or footer rocks as determined from survey and comparison of photos.

Impacts to the channel and to habitat must be carefully monitored. Channel changes occurring following installation can be documented by reviewing an annual survey of cross sections surveyed prior to installation and at the time of completion. Patterns of sediment deposition or scour should be noted. Similarly, changes to available habitat should be documented on a schedule dictated by fish life cycles. For a comprehensive review of habitat-monitoring protocols, refer to Johnson, et al.[8] Habitat-monitoring protocols will likely require a monitoring schedule that is more comprehensive than that required for the integrity of the structure.

Monitoring should be conducted annually at a minimum and following all flows having a return period of two years or greater. Monitoring should be conducted for at least five years after groin installation. Mitigation components of groins must be monitored for the life of the mitigation requirement.

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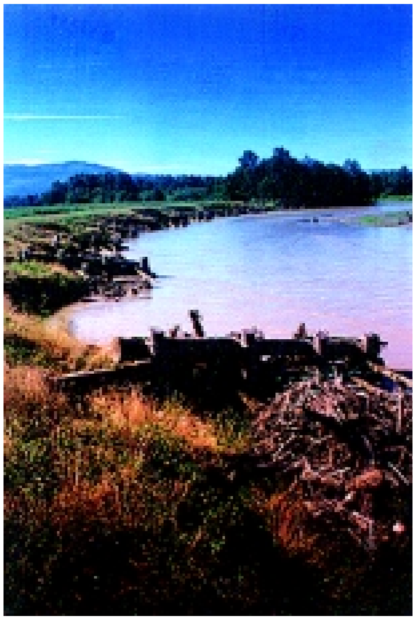
a. Wood Groins with bank reshaping and plantings. During Construction. Wind River. 1999.

b. Wood Groins. Klahowya Creek, Tributary to E. Fork. Nookachamps River. 2001.

c. Rock Groin with woody debris accumulation. Big Quilcene River. 1998.

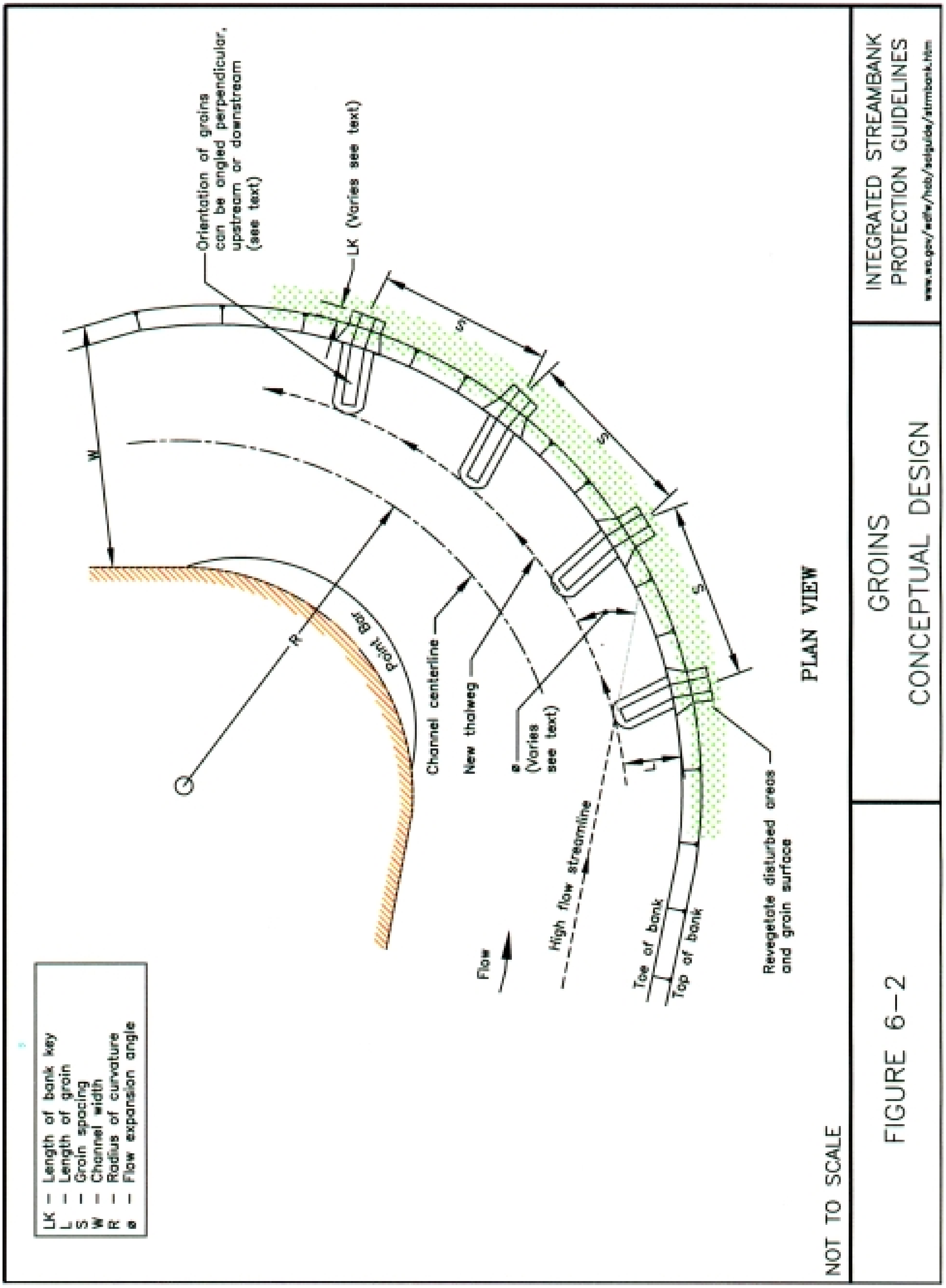
d. Wood Groins. Wind River. One year after construction. Note wood accumulation. 2000.

e. Dolo Groins. Nooksack River. 1998.
Source: Inter-Fluve, Inc.



f. Wood Groins. Nooksack River. 1998.

Figure 6-1. Various applications of groins throughout Washington State.


LK — Length of bank key
L — Length of groin
S — Groin spacing
W — Channel width
R — Radius of curvature
e — Flow expansion angle
NOT TO SCALE
FIGURE 6–2
Orientation of groins can be angled perpendicular, upstream or downstream (see text)
LK (Varies see text)
W
R
S
L
Point Bar
Channel centerline
New thalweg
e (Varies see text)
High flow streamline
Flow
Toe of bank
Top of bank
Revegetate disturbed areas and groin surface
PLAN VIEW
GROINS
CONCEPTUAL DESIGN
INTEGRATED STREAMBANK PROTECTION GUIDELINES

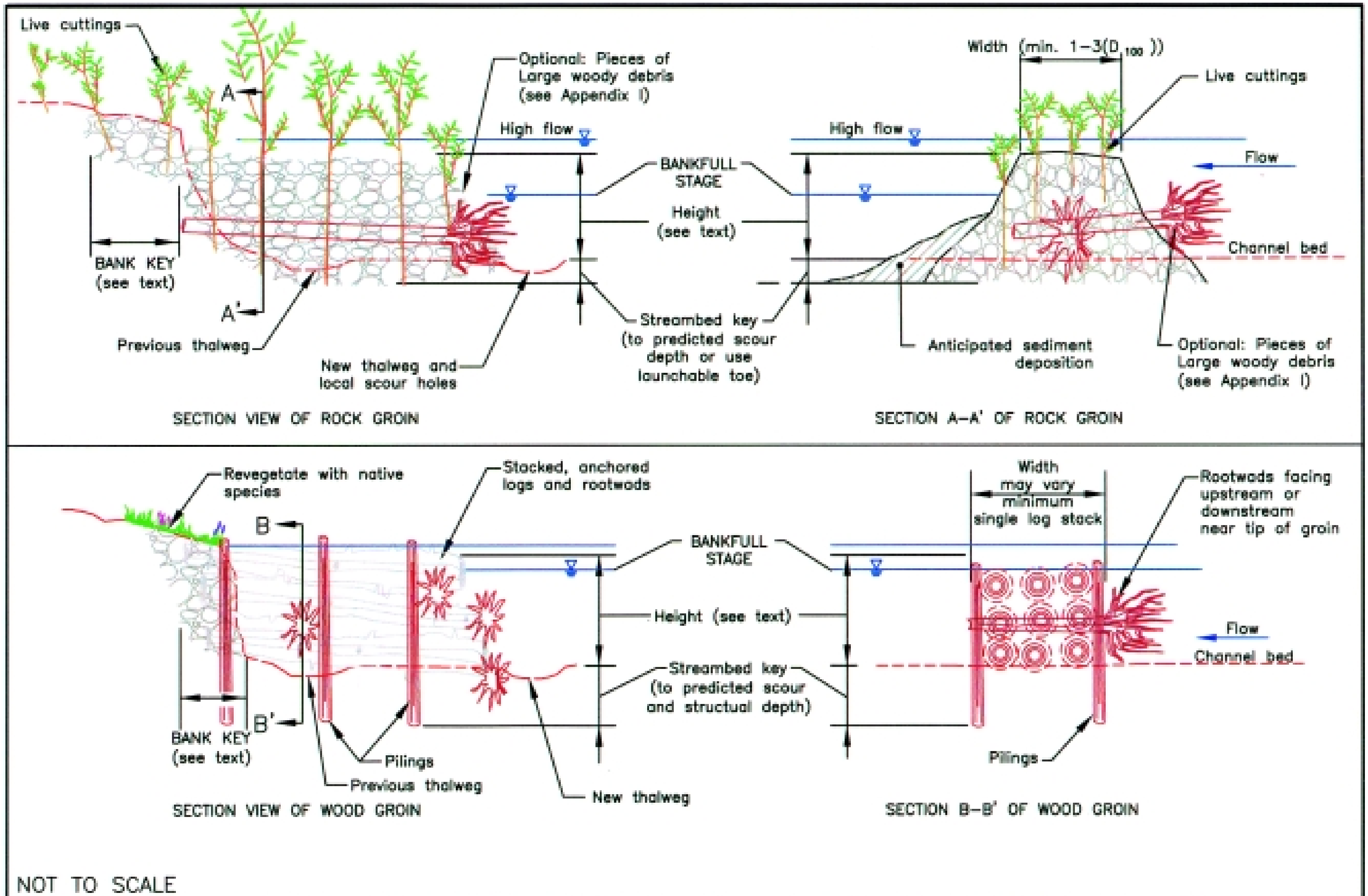


FIGURE 6–3

GROINS
CONCEPTUAL DESIGN

INTEGRATED STREAMBANK PROTECTION GUIDELINES
www.wa.gov/wdfw/hab/ahg/strmbank.htm

Buried Groins

Flow-Redirection Techniques

DESCRIPTION

There are situations where property and structures are not immediately in danger from streambank erosion but are likely to become so in the near future. In such cases, setback alignments can be constructed to protect them. One type of setback alignment is called a buried groin (also called buried rock trenches, transverse dikes or sills). Buried groins are structures embedded in the ground, inland from the eroding bank. If channel erosion reaches the buried groin, the groin will stop or reduce the rate of erosion from progressing farther toward the property or structure to be protected. Once exposed, buried groins redirect flow away from a streambank and reduce flow velocities near the bank to protect it from erosional forces. Buried groins become groins once they are exposed (see the discussion in this chapter addressing *Groins* for additional information). Buried groins can also provide the benefit of a wider channel-migration corridor for continued, natural channel evolution.

APPLICATION

Buried groins are installed between the eroding bank and the structure or property at risk, and they are most effective when positioned as close to the stream's migration corridor boundary as possible. These structures can be used where natural stream- and/or floodplain-corridor function is a priority, and some channel migration is allowable. Buried groins can be used as an integrated, medium- to long-range planning tool. Buried groins can also be used in concert with exposed groins placed along the bank of an active channel. If erosion is likely to extend downstream or upstream from the groins, buried groins can be extended along the predicted future location of the streambank for added protection.

Buried groins can be integrated with deformable, biotechnical or experimental treatments at eroding banks to promote natural, channel-migration processes through gradual, controlled erosion. Buried groins can be placed inland from these other bank treatments at a location beyond which continued erosion and channel migration is not desirable.

Specific site and reach limitations will help determine whether or not buried groins are a suitable solution (see Chapter 2, *Site Assessment* and Chapter 3, *Reach Assessment* for further guidance). Buried groins are appropriate for sites where the mechanism of failure is toe erosion. They can be used to establish or define a migration corridor, and they can be used in combination with grade-control structures (e.g., a porous weir or drop structure) in a degrading channel. Refer to the screening matrices in Chapter 5, *Identify and Select Solutions* for further guidance on the applicability of buried groins.

Variations

Buried groins are typically constructed from large rock. However, they can also be constructed with large woody debris (see Appendix I, *Anchoring and Placement of Large Woody Debris*). Buried groins can be constructed to be either impermeable or permeable. The permeability of a buried groin depends upon stream characteristics, the desired reduction in flow velocity and the radius of curvature. Impermeable groins are typically constructed using riprap, whereas permeable groins are constructed from a variety of materials such as wood pilings, large woody debris and concrete doloes.

Emergency

Buried groins can be used during emergency situations since they are set back from the affected channel bank, allowing for construction to occur away from flood flows. However, they typically require heavy equipment for installation and substantial amounts of excavation and construction materials.

EFFECTS

The effects of buried groins on the channel and floodplain are essentially negligible until the channel erodes and exposes them. Once this occurs, buried groins function and cause similar effects as exposed groins that are constructed in an active channel (refer to the technique described in this chapter called *Groins* for additional information). Once the buried groins are exposed, they create roughness along the new bank and maintain the thalweg alignment along their tips. Scour holes will also form off the tips of the groins.

DESIGN

Conceptual design drawings of groins are shown in *Figure 6-4* and *Figure 6-5* at the end of this technique discussion.

The design of buried groins is like that of standard groins, with a few important differences. The primary difference between standard groins and buried groins is the location within the channel corridor where they are placed. Standard groins are constructed along an active bank, whereas buried groins are positioned at a location inland from the active bank. Due to their setback location, designing buried groins is more difficult than standard groins because you cannot determine in advance precisely what the channel's physical characteristics (dimensions, alignment, flow velocity and patterns, etc.) will be when the groins are eventually exposed. Given the uncertainty of future channel characteristics, scour depth is also difficult to predict. To compensate for this uncertainty, buried groins can be constructed with a launchable toe to protect against scour rather than trying to predict how deep the scour will go and then installing the groins to that depth. Estimates for the required amount of extra rock for the launchable toe can be made on the basis of conservative scour-depth calculations for the existing channel.[1] Because it is difficult to anticipate future conditions, buried-groin design needs to be somewhat conservative in order to address as many potential conditions as possible. The section in this chapter that discusses *Groins* provides further details on exposed-groin design, including depth and height of installation.

The orientation, length and spacing of buried groins are determined in a similar manner to that used for exposed groins that are installed along an active channel. However, because the orientation, curvature and location of the channel when it eventually intersects the buried groins cannot be known with certainty, designs will have to compensate for this uncertainty. The recommended design process is similar to that for traditional, impervious rock groins.[2,3]

Location

Careful analysis is required to determine appropriate locations for installation of buried groins. The intended function of the buried groins will influence the placement location. For instance, if the buried groins are intended to protect property or structures from an eroding channel bank, it's easy to see that the buried groin needs to be located somewhere between the property to be saved and the eroding bank. It's not as easy to determine correct positioning when buried groins are to be used to define a meander migration corridor or to provide back-up protection for deformable, biotechnical, or other experimental bank treatments. Under both circumstances, placement will require an understanding of the geomorphic processes within the reach and adjacent reaches (see Chapter 3 and Appendix F, *Fluvial Geomorphology*). A reach assessment can help establish realistic meander-corridor limits. Once the limits of a migration corridor are determined, buried groins can be placed at the boundary to prevent erosion outside the corridor.

Material Sizing

Determining the most suitable size of rock for an impermeable-rock buried groin can be accomplished using a variety of methods. Rock sized for typical bank-revetment riprap is too small for groins. If a hydraulic analysis of the site has been performed, flow velocity will be known and the Isbash relationship can be used to size the rock.[1] The Isbash relationship is a time-tested equation used for designing bridge abutments. Since groins have the same effect as bridge abutments in that they constrict a channel, the Isbash-relationship calculation can be applied to determining rock size for groins. Another way of calculating the correct size of rock to be used in the groin is to use a method developed by the Natural Resources Conservation Service and the U.S. Army Corps of Engineers. The conservation service recommends using a D_{50} equal to 1.5 to two times the size determined from riprap design for bankfull flow.

Rock should be angular, and not more than 30 percent should have a length exceeding 2.5 times its thickness. Rock should be well graded with only a limited amount of material less than half the median rock size. Large woody debris installed in groins should be submerged for habitat value and to reduce the rate of decay. Refer to Appendix I for guidance.

Permeable buried groins can be constructed from logs, a combination of logs and rock, or concrete doloes. Log groins are typically constructed using wooden or steel piles, wood cross-logs and rootwads. Steel piles have the advantage of being stronger, allowing better (deeper) penetration through gravel or cobble subsurface materials, and being free of buoyant forces. The obvious disadvantage to steel piles is their longevity - they are likely to far outlive the other components of the groin. Cross-logs are typically branchless logs cabled across the piles to form a fence-like structure. Rootwads can be included in the structure to add complexity. See Appendix I and the discussion in this chapter addressing *Engineered Log Jams*.

Orientation

The orientation of flow as a channel migrates into buried groins cannot ordinarily be determined in advance with any degree of certainty. Because of the uncertainty of future channel dimensions, buried groins should be aligned perpendicular to the existing migration corridor margin. In situations where there is a high degree of certainty, then buried groins can be angled downstream or upstream. Refer to the technique described in this chapter called *Groins* for additional information.

Length

Groin length is defined as the projected length of the groin perpendicular to the flow direction. The length of impermeable groins typically does not exceed 15 percent of the bankfull channel width.[1] In the absence of accurate information about future channel dimensions, the length of buried groins can be based instead on the existing bankfull-channel width.

Spacing

Spacing between buried groins depends upon project objectives and should be determined as a function of groin length and permeability. Maximum spacing is determined by the intersection of the tangent flow line with the bank, assuming a simple curve; however, the future channel curvature cannot be predicted with great certainty. The maximum spacing is not recommended, but is a reference for designers. Flume studies show that stream flow expands at an angle of about 17 degrees out of a channel constriction created by impermeable groins.[2] The next downstream groin is placed at the point where the thalweg would intersect the bank if there were not a downstream groin. This is roughly 3.3 times (tan 73°) the length of the groin from the point of contact with the bank and its tip. Groins have been successfully placed at about two to five times their length, which adds a range to the previous result and allows some flexibility in locating them.

BIOLOGICAL CONSIDERATIONS

Mitigation Requirements for the Technique

Placement of buried groins impacts riparian function and eventually affects dynamic river processes, including channel migration. Sediment and woody-debris inputs will be reduced once the buried groins are exposed, representing a lost opportunity for development of habitat complexity and diversity. Mitigation of these impacts can include the incorporation of large woody debris into the construction of buried groins. Live, woody, plant cuttings can be planted into the buried groins once they are exposed as a means of enhancing riparian function. Segments of bank located between groins can also be revegetated with both woody and herbaceous species to replace lost riparian function. Placement of large woody debris between groins is not recommended because this is typically a depositional area that lacks sufficient depth for habitat development. Locating buried groins such that the greatest migration corridor width is attained, within geomorphic or infrastructure limitations, will maximize mitigation for lost opportunity impacts. Refer to Chapter 4, *Considerations for a Solution* and Matrix 3 in Chapter 5 for more detail on mitigation needs for this bank treatment.

Mitigation Benefits Provided by the Technique

Buried groins do not provide any immediate mitigation benefit. By installing groins at a location that is setback from the active channel, allowance can be made for natural channel and floodplain function until the groins are exposed. The channel can migrate naturally to the limits defined by the buried groins. Buried groins can also serve as a back-up structure that enables application of a less structural type of treatment, such as biotechnical techniques, at the eroding bank face. If the treatment along the bank face begins to fail, the buried groins will provide needed stabilization until repairs can be initiated.

Buried groins should be combined with biotechnical or deformable bank-stabilization techniques and riparian-buffer management. They provide a mechanism for protecting a riparian buffer against erosive forces that could result from rapid channel migration until vegetation in the buffer has become mature. Buried groins constructed with large woody debris will provide habitat complexity and diversity along the active bank once the groins are exposed. Buried groins implemented in association with a riparian buffer are a good example of an integrated streambank-protection strategy that provides for natural channel and floodplain evolution.

RISK

Habitat

Buried groins represent a risk of lost opportunity for development of habitat diversity. Once the channel has migrated into the groins and exposed them, gravel and woody debris recruitment will be reduced. Depending upon their location within the channel migration zone, buried groins may reduce or prevent development of diverse, off-channel habitat, including side channels and swales, wetlands or ponds.

Risks to in-channel habitat are the same for buried groins as they are for exposed groins once the buried groins have been exposed. If there is a spawning area on the margin of a point bar, in the tailout of a bank scour pool or on the river side of the thalweg on a more straight river stretch, the spawning area is at risk of becoming scoured. This can be a severe problem for fish, because scour can kill eggs and alevins that are still in the gravel; however, as the bed and bars stabilize over time, these scour impacts should become minor.

A survey of over 600 bank-stabilization projects in western Washington assessed five different types of bank treatments for their impacts and/or benefits to fish.[4] Rock groins and rock groins with large woody debris were two of the treatments evaluated. Stabilized sites were compared with similar, naturally stable, untreated control sites in the same river. Bank treatments that incorporated large woody debris were the only ones that consistently had greater fish densities than their corresponding control areas during spring, summer and winter. Fish densities were lower at groins than their controls during the spring and summer, but they were greater during the winter.

Study results found that fish densities were lower at stabilized banks except those with a large-woody-debris component. Fish densities were positively correlated with total surface area of large woody debris at all sites. Based on these results, such debris should be incorporated into buried groins whenever practical. On the other hand, most large woody debris used in surveyed groin projects was found between the groins. The area between groins is a depositional area that typically becomes more shallow over time. For this reason, these areas often lacked sufficient depth for rearing habitat. Additionally, large woody debris incorporated directly into the groins was often placed too high with respect to summer water depths. Since bed elevations and corresponding water depths cannot be accurately predicted for the point at which the channel exposes the buried groins, it is recommended that large woody debris be incorporated at a variety of elevations. This will improve the chances that at least some beneficial habitat will be developed.

Infrastructure

Buried groins offer minimal risk to infrastructure because the typical placement of buried groins is away from the active channel. However, their location must anticipate meander-migration patterns. For instance, if the channel migrates in a different pattern than expected, the buried groins may not intercept the channel, leading to a continued threat to infrastructure from channel migration.

Once they are exposed, buried groins can be undermined if scour depth is not accounted for in the design process. Buried groins should be adequately keyed into the bank and bed. Positioning keys for buried groins may be more difficult than positioning the groins themselves, because there is typically no active channel margin to help define placement depths and distances for the key.

Reliability/Uncertainty of Technique

There is little available research on the long-term performance of buried groins. They are a relatively new technique for streambank protection. Furthermore, because groin design is typically dependent on existing channel shape and buried groins are intended to be effective for some eventual and unknown channel alignment, their design assumes a high degree of uncertainty. Design processes will likely become more refined as more research is accomplished. Monitoring and performance reporting should be encouraged to aid the further development of this technique by future practitioners. Refer to Appendix J, *Monitoring* for a further discussion of monitoring.

CONSTRUCTION CONSIDERATIONS

Materials Required

Buried groins can be constructed using a variety of materials. Rock is the most common type of material used in Washington; however, large woody debris and concrete doloes have also been applied.

Timing Considerations

Buried groins can be constructed during virtually any flows, as they are separate from the active channel. However, they are best constructed during low groundwater periods, particularly if wood is used, in which case buoyancy will need to be addressed. Critical periods in resident and anadromous fish life cycles such as spawning or migration should be avoided. Instream work windows vary among fish species and streams. Contact the Washington Department of Fish and Wildlife's Area Habitat Biologist for information on work windows (see Appendix B, *Washington Department of Fish and Wildlife Contact Information*). Further discussion of construction timing and dewatering can also be found in Appendix M, *Construction Considerations*.

Cost

Because buried groins are not constructed within the active channel, there are no costs associated with dewatering or sediment control for this technique. Therefore, the total cost is less than for a conventional riprap or groin design. However, the cost of installation per structure may be greater than its counterparts because more excavation is required, and disposal of excavated material is also required.

The major cost elements of buried-groin construction include access, materials, installation and disposal. For further information on the costs of these components and specific construction materials, refer to Appendix L, *Cost of Techniques*. Cost of individual buried groins may vary from $2,000 to $5,000 depending upon their size and site-specific factors.

MAINTENANCE

Maintenance of buried groins should be minimal until they are exposed by channel flows. Once exposed, maintenance activities include replacement of construction materials (e.g., rock, logs) that shift or are removed by high flows. Erosion along the perimeter of the groin, as well as along the streambank between groins, should be closely monitored and evaluated for need of repair. Buried groins installed as launchable material may require considerable maintenance and adjustment, including addition of rock, once exposed.

Buried groins will require reclamation and revegetation efforts in areas disturbed by their installation.

MONITORING

Monitoring of buried groins should begin with accurate documentation of their placement location, configuration and dimensions. All surveys should be tied to a monument or benchmark situated outside the risk area. Measurements can also be taken from their placement location to the active channel in order to evaluate rates of bank erosion. Prior to being exposed, buried groins should be inspected annually and following all flows greater than a two-year return period to determine whether they have become exposed. Once exposed, monitoring should be conducted as detailed in this chapter under the technique, *Groins*. For a comprehensive review of habitat-monitoring protocols, refer to Johnson, et al.[5] Habitat-monitoring protocols will likely require a monitoring schedule that is more comprehensive than that required for the integrity of the structure.

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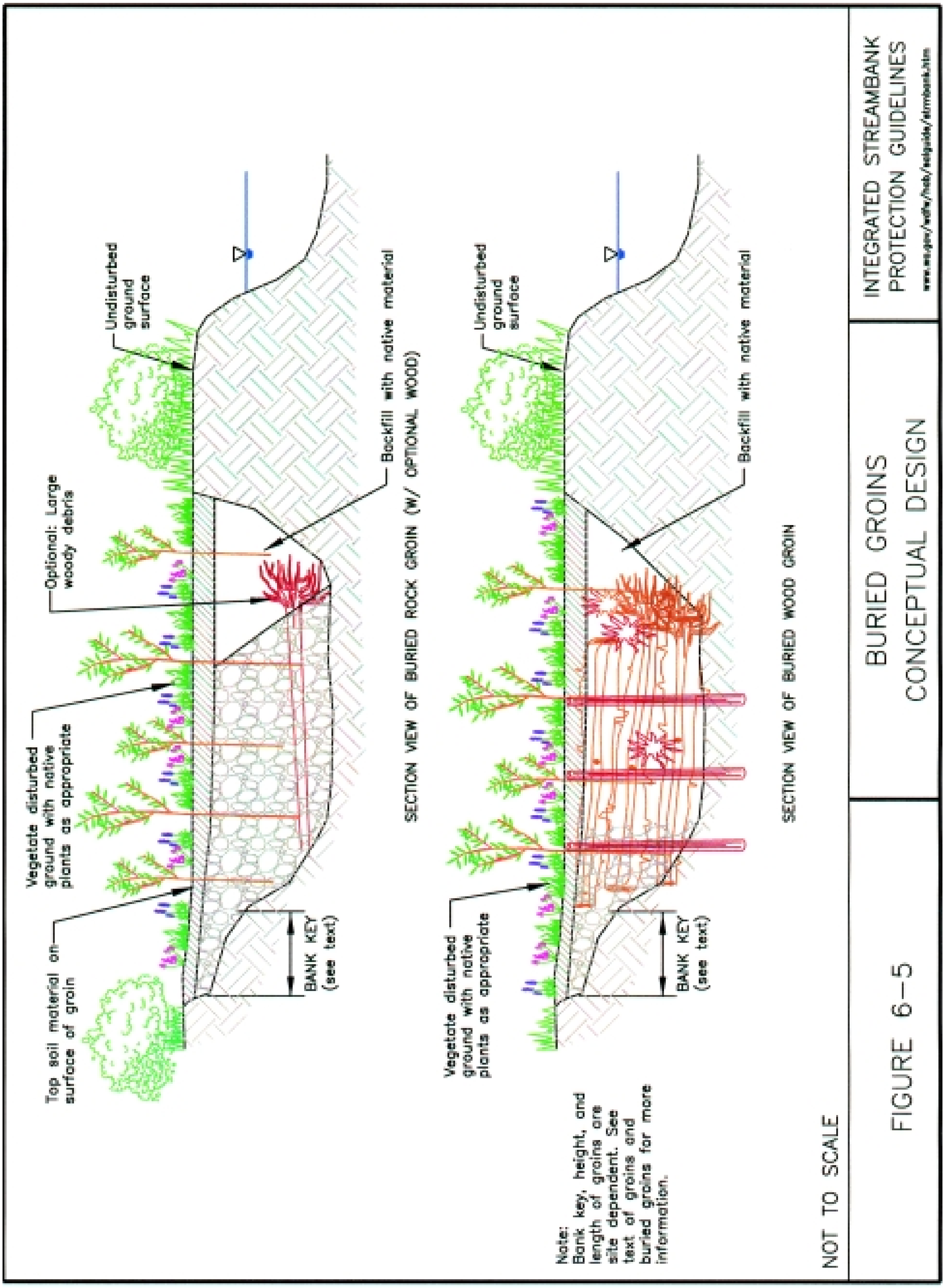
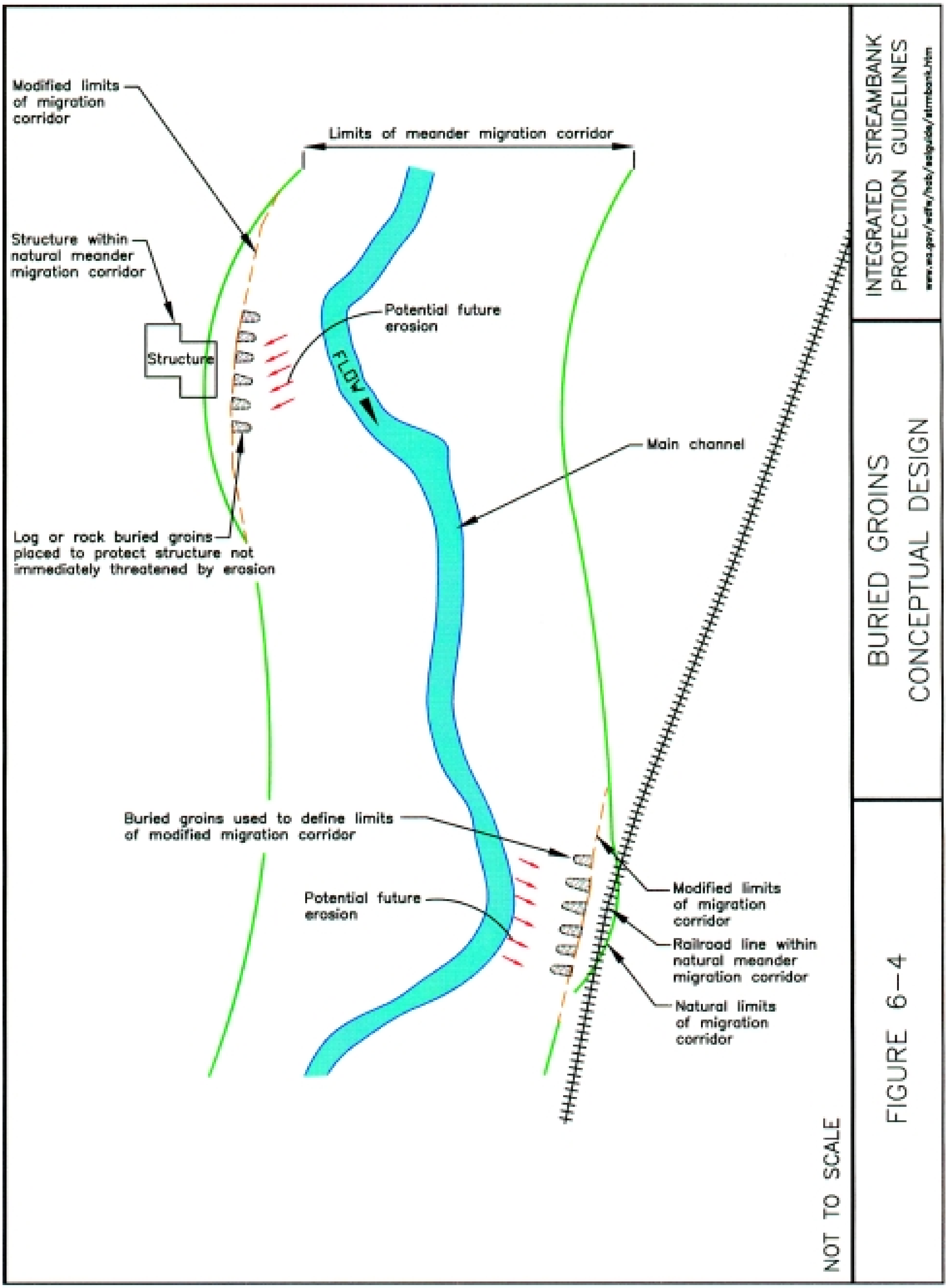

Top soil material on surface of groin
Vegetate disturbed ground with native plants as appropriate
Optional: Large woody debris
Undisturbed ground surface
Backfill with native material (W/ OPTIONAL WOOD)
BANK KEY (see text)
SECTION VIEW OF BURIED ROCK GROIN (W/ OPTIONAL WOOD)
Vegetate disturbed ground with native plants as appropriate
Undisturbed ground surface
Backfill with native material
BANK KEY (see text)
SECTION VIEW OF BURIED WOOD GROIN
Note:
Bank key, height, and length of groins are site dependent. See text of groins and buried groins for more information.
NOT TO SCALE
FIGURE 6–5
BURIED GROINS
CONCEPTUAL DESIGN
INTEGRATED STREAMBANK
PROTECTION GUIDELINES


Modified limits of migration corridor
Limits of meander migration corridor
Structure within natural meander migration corridor
Structure
Potential future erosion
FLOW
Main channel
Log or rock buried groins placed to protect structure not immediately threatened by erosion
Buried groins used to define limits of modified migration corridor
Potential future erosion
Modified limits of migration corridor
Railroad line within natural meander migration corridor
Natural limits of migration corridor
NOT TO SCALE
INTEGRATED STREAMBANK PROTECTION GUIDELINES
BURIED GROINS CONCEPTUAL DESIGN
FIGURE 6–4

DESCRIPTION

Barbs, also called vanes or bendway weirs, are low-elevation structures that are projected into the channel from a bank and angled upstream to redirect flow away from the bank and to control erosion.[1] Barbs function similarly to weirs in that flow spills over the barb toward the center of the channel, reducing the water velocity near the bank. Barbs also increase channel roughness, which dissipates energy, reduces channel-bed shear stress and interrupts sediment transport. Barbs are typically constructed from rock, large woody debris or a combination of both. *Figure 6-6* (at the end of this technique discussion) shows various applications of barbs throughout Washington State.

Barbs and groins are often mistaken for one another because they look similar, and both function to redirect flow. The primary difference between groins and barbs is that groins are higher-profile structures that tend to deepen the thalweg and narrow the stream, while barbs have less of an effect on the cross-sectional shape of the stream. Groins also provide greater roughness and more channel constriction, which results in greater scour depths and increased flood stage. Similar to groins, barbs induce scour near their tips, and scour holes are likely to form in that location. Unlike groins (which are seldom completely submerged), barbs may experience scour along their downstream edge due to overtopping flows plunging over the barb crest. Depending upon factors such as the angle of attack of flood flows and depositional patterns, eddies may form between barbs in some circumstances, which may lead to scour (erosion) along the bases of barbs or adjacent streambanks. In general, however, deposition can be expected to occur between barbs that are properly designed and installed in an appropriate location.

APPLICATION

Barbs are used to redirect erosive flows away from a streambank or a bridge pier, or to direct water through a culvert or under a bridge. Barbs are often applied in combination with other types of bank-protection techniques. For example, the effect of barbs on near-bank hydraulics allows biotechnical techniques such as bank reshaping and planting to succeed. This allows an integrated bank treatment that provides greater habitat complexity and diversity. Barbs may also be used to complement downstream bank-protection techniques by directing the thalweg away from the banks. Barbs range in a continuum of size from short barbs to those that span the entire channel width (e.g., grade-control structures).[1]

Barbs are appropriate for sites where the mechanism of failure is toe erosion. To ensure long-term function, they are best applied on long, uniform stream bends where the upstream flow approach remains relatively constant over time. They are inappropriate in aggrading, degrading or high-gradient channels. Aggrading reaches may deposit sediment around and over the barbs, reducing or eliminating their hydraulic effect. In degrading reaches, barbs may be undermined, causing them to fail. Barbs are not recommended in streams with gradients over two percent; however, they may work in smaller, high-gradient streams and may not work in large rivers with a shallower slope.

Barbs should be avoided where the potential exists for an avulsion to occur. In addition, at some point, the radius of curvature may become too small for barbs to be a suitable technique to use. In tight-radius bends, localized hydraulics may preclude proper functioning of barbs. Refer to the screening matrices in Chapter 5, *Identify and Select Solutions* for more guidance on the applicability of barbs based on the mechanism of failure and causes of streambank erosion.

Emergency

Because barb materials must be positioned with precision, constructing barbs during flood conditions is not recommended. However, barbs can be installed immediately following a flood event if its application is appropriate.

EFFECTS

The intent of barbs is to protect a bank while keeping the effects of turbulence, scour and roughness to a minimum. Barbs use weir hydraulics of flow passing over the structure to disrupt the secondary currents across the stream bottom and redirect flow away from the bank.[2] Secondary currents result from the friction of viscous fluid flowing across the channel bed and banks. Secondary currents have a primary role in bank erosion, and barbs force these currents to flow perpendicular to their normal erosive course. In other words, barbs work hydraulically to reduce the erosive forces acting on a streambank.

DESIGN

Conceptual design drawings are shown in *Figure 6-7* and *Figure 6-8*.

Orientation

The angle of the barb to the upstream bankline tangent typically ranges from 50 to 85 degrees. Flow is redirected from the barb in a perpendicular direction to the barb axis or the downstream face if the sides are not parallel. Channel bends with smaller radii of curvature will require smaller barb angles to meet this criterion.

Length

The length of a barb should provide bank protection but not adversely confine the channel. In order for barbs to affect the dominant flow pattern, they must extend to the thalweg. The Natural Resources Conservation Service recommends that the effective length of a barb should not be greater than 25 percent of the bankfull channel width.[3] The effective length is defined as the projected length of the barb perpendicular to the flow direction. A length of 1.5 to two times the distance from the bank to the thalweg has proven satisfactory on some bank stabilization projects.[2] It should be noted that, as barb length increases, scour depth and flow concentration at the tip increase.

Spacing

Barbs are most commonly constructed in a series; however, individual barbs can be used for localized flow redirection. Barb spacing is affected by barb length, the ratios of barb length to channel width and the bend radius of curvature to channel width. Given that flow will be directed in a perpendicular direction from the downstream barb face, the subsequent barb should be placed such that it captures this flow near its center before the flow impinges on the bank. Spacing can be computed based on the following guidance formulas[4,5]:

$$Spacing = 1.5L(R/W)^{0.8}(L/W)^{0.3}$$
$$Spacing = (4 \text{ to } 5)L$$

L = Length
R = Bend Radius
W = Channel Width

Spacing affects the roughness through a bend. A large number of closely spaced barbs are hydraulically smoother than fewer barbs occupying the same distance. Placement of barbs should extend beyond the area of bank erosion. To train flow away from the bank, the barb field should begin upstream of the point where flow impinges on the bank. The first barb in the series typically receives the greatest pressure and should be built accordingly. Depending upon site-specific conditions, this may be well above where the actual erosion is occurring. At the downstream end of the field, the flow should be directed out into the channel.

Height

Barb height is determined by analyzing flow depths at the project site. The height of the barb should also be below the ordinary high water mark and should be equal to or above the mean low-water level (*Figure 6-8*).[2] Hydraulically, a barb needs to be of sufficient height to influence the secondary bed currents. Barbs are intended to function like weirs; therefore, the top of the barb should be flat, or nearly flat, with a maximum slope into the channel of 5:1. The flat weir section typically transitions into the bank on a slope of 1.5:1 to 2:1. Barbs constructed at or above the design high-water elevation are considered groins and should be designed as such.

Width

For rock barbs, the top width ranges from one to three times the D_{100} rock size. Barb width may need to be increased to accommodate equipment for constructing long barbs or for working in large rivers. Wider structures will result in a more uniform weir effect and should be used if a deep scour hole is anticipated downstream of the barb. Barb width for nonrock barbs is generally dictated by the construction materials.

Key

Barbs should be properly keyed into the bank to prevent flanking of the structure due to erosion in the near-bank region. Typically, the key length is about half the length of short barbs (10 to 20 feet in length) and one-fifth the length of longer barbs (greater than 50 feet) and should not be less than 1.5 times the bank height.[2] The Natural Resources Conservation Service guidelines recommend a minimum key length of eight feet or 4(D_{100}), whichever is greater.[5]

Barbs should also be keyed into the channel bed or constructed with a launchable toe. The key depth can be determined by calculating the expected scour depth around the tip of the barb (refer to Appendix E, *Hydraulics* for guidance on scour depth calculations). If a bed key is not incorporated or is too shallow, scour may erode the bed material downstream of the barb, causing barb materials to fall into the scour hole. Dewatering will likely be required during excavation of the bed key. A launchable toe counters scour effects by placing additional rock material along the base of the barb, which will launch into a scour hole if one develops. The launchable approach may preclude having to perform detailed scour calculations; however, caution should be applied because additional rock can be inappropriately placed on beds that do not scour, resulting in greater impact to the channel and unnecessary costs associated with the extra rock.

Wooden pile barbs also need to be keyed into the bank and the channel bed. Piles should be driven to a depth into the streambed adequate to resist hydraulic forces, the impact of floating debris and buoyant forces at the design discharge, assuming maximum scour is attained. This depth will vary according to site hydraulics, expected impact of floating debris and subsurface materials. Rock can be placed along the base of a wooden barb to counter scour that might otherwise destabilize the structure.

BIOLOGICAL CONSIDERATIONS

Mitigation Requirements for the Technique

Barbs redirect flow away from an eroding bank and disrupt erosive secondary currents, which, in turn, affects sediment-transport patterns, especially in the near-bank region. Realignment of flow and redistribution of sediment will often impact existing spawning areas. A decrease in bank erosion will reduce periodic inputs of gravel and woody debris into the channel, which represents a lost opportunity for continued development of habitat complexity. Riparian function is also impacted by replacing riparian vegetation with a barb.

One way to partially mitigate for habitat loss is to incorporate large woody debris into the exposed portion of the barb at the bank and in the barb key. Refer to Appendix I, *Anchoring and Placement of Large Woody Debris* for additional information on how to position large woody debris. Live, woody plant cuttings can also be incorporated into this part of the barb. Segments of bank located between barbs can also be revegetated with both woody and herbaceous species to replace lost riparian function.

Refer to Chapter 4, *Considerations for a Solution* and Matrix 3 in Chapter 5 for more detail on mitigation needs for this bank treatment.

Mitigation Benefits Provided by the Technique

Barbs create channel roughness, a feature that has been lost in many rivers over the last 100 years through the removal of large woody debris. The added roughness dissipates energy and creates turbulence and scour holes, which provides cover for fish. Barbs produce a low-energy environment where fish can seek refuge at periods of high flow. They produce useful scour holes, providing micro-habitat at low flow, especially in rivers with high width-to-depth ratios.

Untreated banks may exist between barbs, providing soil for trees close to the stream and a shallow, low-velocity area with small woody debris and leaf litter. Barbs can include large woody debris in their structure and may eventually recruit floating large woody debris. Refer to Matrix 3 in Chapter 5 for more detail on the mitigation benefits of this bank treatment.

RISK

Habitat

If there is a spawning bed on the margin of a point bar or in the tailout of a bank-scour pool, the spawning bed may be scoured by the effects of a barb. The existing, unarmored bank may be sustaining a deep, lateral scour pool with overhanging vegetative cover and woody debris. This might be the only significant pool habitat for some distance. Placement of barbs may eliminate this habitat. The habitat-generating value of the barbs will likely not compensate for elimination of the pool habitat.

A survey of over 600 bank-stabilization projects in western Washington assessed five different types of bank treatments for their impacts/benefits to fish.[6] Rock barbs and rock barbs with large woody debris were two of the treatments evaluated. Stabilized sites were compared with untreated, control sites in the same river that were naturally stable and as similar to the stabilized site as possible. Bank treatments that incorporated large woody debris were the only types that consistently had greater fish densities than their corresponding control areas during spring, summer and winter. Fish densities were generally lower at barbs than their controls during the spring and summer, but greater during the winter.

Study results indicate that fish densities are lower at stabilized banks except those with a large-woody-debris component. Fish densities were positively correlated with total surface area of large woody debris at all sites. Based on these results, large woody debris should be incorporated into barbs whenever practical. Most large woody debris used in surveyed barb projects was found between the barbs in a depositional area with insufficient depth for rearing habitat. Care should be exercised when incorporating large woody debris to ensure that it is placed at a suitable elevation within the barb. Appendix I provides guidance on anchoring large woody debris into barbs.

Infrastructure

During construction, avoid disturbing existing vegetation. Position barbs between trees and shrubs, if possible, rather than removing the vegetation. Minimize bank sloping and armoring between barbs. If the bank between barbs is un-vegetated or newly armored, revegetation should be initiated on the slope and top of the bank.

Reliability/Uncertainty of Technique

The Natural Resources Conservation Service has design standards for stream barbs, and many of them have been constructed in Washington State. The U. S. Army Corps of Engineers has researched and built a bendway weir. The Corps' Waterways Experiment Station in Vicksburg, MI, has conducted several physical-model studies on the use of bendway weirs to improve navigation on large rivers, and research is providing valuable information on their use and effectiveness.

Barbs and bendway weirs are a little different, and no quantitative assessment of their performance has been done. The Federal Highway Administration is currently engaged in a survey of barbs. This is a developing field, and the limits of various design parameters have not been established.

CONSTRUCTION CONSIDERATIONS

Materials Required

Typical materials used in the construction of barbs are rocks and logs. Rock should be angular and the size of rock can be determined by appropriate riprap design procedures. Rock sized for typical bank revetment riprap is too small for barbs. The Natural Resources Conservation Service recommends using a D_{50} rock size that is two times the D_{50} rock diameter determined using standard riprap-design procedures for continuous riprap at bankfull conditions.

Log barbs have typically been constructed using wooden or steel piles, wood cross-logs and rootwads. Steel piles have the advantage of being stronger, allowing better (deeper) penetration through gravel or cobble subsurface materials, and they are free of buoyant forces. The obvious disadvantage to steel piles is their longevity - they are likely to far outlive the other components of the barb. Cross-logs are typically branchless logs cabled across the piles to form a fence-like structure. Rootwads can be included in the structure to add complexity. Large woody debris installed in barbs should be submerged below the ordinary high-water line for habitat value and longevity. Refer to Appendix I for guidance.

Woody vegetation should be planted in the barb at proper hydrologic zones and growing medium. Generally, live cuttings are the most suitable. Refer to Appendix H, *Planting Considerations and Erosion-Control Fabrics* for more information.

Timing Considerations

Barbs are best constructed during low flow, when dewatering is possible and when resident and anadromous fish are less likely to be impacted by construction activities. In order to install rock or logs to the depth of scour, excavation within the channel bed will be necessary and, consequently, will require temporary dewatering systems. Keying into the streambed by constructing a launched toe may also require dewatering. Dewatering allows for ease of installation and limits siltation of the stream during construction. This can be accomplished with a coffer dam during low water.

Critical periods in salmonid life cycles, such as spawning or migration, should be avoided. Instream work windows vary among fish species and streams. Contact the Washington Department of Fish and Wildlife's Area Habitat Biologist for information on work windows (see Appendix B, *Washington Department of Fish and Wildlife Contact Information*). Further discussion of construction timing and dewatering can also be found in Appendix M, *Construction Considerations.*

Cost

The main function of barbs is to direct flow away from the bank, thus modifying flow patterns in the near-bank region to encourage sediment deposition and reduce bank erosion. Corresponding decreases in velocities and shear stresses along the bank minimize the need for bank protection to be applied between barbs. Therefore, barbs, in combination with other bank treatments, may protect a streambank more effectively and at less cost than traditional bank-revetment measures. The cost is generally less than that for a conventional riprap or groin design.

The major cost components of barb construction include access, materials, dewatering and installation. For further information on the costs of these components and specific construction materials, refer to Appendix L, *Cost of Techniques*. Cost of individual rock barbs may vary from $2,000 to $5,000 depending upon their size and upon site-specific factors.

MAINTENANCE

Maintenance of barbs may include replacement of construction materials (e.g., rock, logs) that shift or are removed by high flows. This may include replacement of nonsurviving plant material. Barb materials lost to high flows should be replaced before damage occurs to the bank or structures located between the barbs.

Erosion along the perimeter of the barb and at the key should be closely monitored and evaluated for need of repair.

MONITORING

Because barbs involve impacts to the channel and banks, they will require comprehensive monitoring of the integrity of the structures, channel and bank features and in-channel habitat. Monitoring of barb projects should be initiated prior to construction, with baseline-conditions surveys of the physical channel, its banks and its habitat value. This should include five cross-sections at intervals equal to the channel width upstream, five downstream and one through each barb at a minimum. This will allow comparison of modified conditions to preproject conditions. Additionally, monitoring should include detailed as-built surveying and photo documentation from fixed photo points of the project area and upstream and downstream reaches to allow for evaluation of performance relative to design. Details on development of a monitoring plan are discussed in Appendix J, *Monitoring*.

Monitoring of barb structures should include preproject and subsequent annual surveys of key members and visual assessments of their configuration, dimensions and hydraulic function. The general integrity of the structures should be evaluated, including the identification of any significant settling of header or footer rocks as determined from survey and comparison of photos.

Impacts to the channel and to habitat must be carefully monitored. Channel changes occurring following installation can be documented by reviewing an annual survey of cross sections surveyed prior to installation and at the time of completion. Patterns of sediment deposition or scour should be noted. Similarly, changes to available habitat should be documented on a schedule dictated by fish life cycles. For a comprehensive review of habitat-monitoring protocols, refer to Johnson, et al.[7] Habitat-monitoring protocols will likely require a monitoring schedule that is more comprehensive than that required for the integrity of the structure.

Monitoring should be conducted annually at a minimum and should be conducted following all flows having a return period of two years or greater. Monitoring should be conducted for at least five years after barb installation. Mitigation components of barbs must be monitored for the life of the mitigation requirement.

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7 Johnson, D. H., N. Pittman, E. Wilder, J. A. Silver, R. W. Plotnikoff, B. C. Mason, K. K. Jones, P. Roger, T. A. O'Neil and C. Barrett. 2001. Inventory and Monitoring of Salmon Habitat in the Pacific Northwest - Directory and Synthesis of Protocols for Management/Research and Volunteers in Washington, Oregon, Idaho, Montana, and British Columbia. Washington Department of Fish and Wildlife, Olympia, WA.

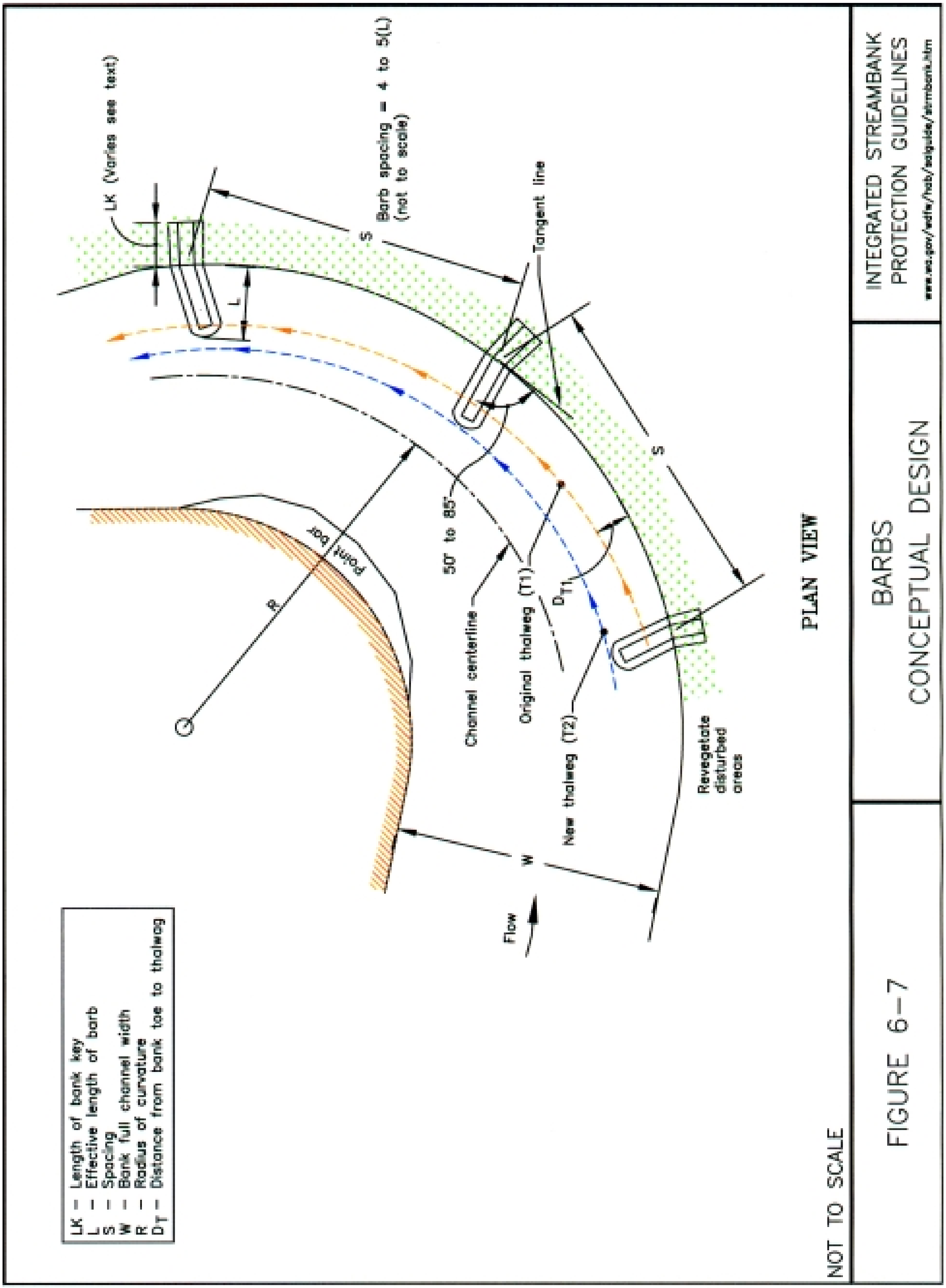
a. Teanaway River, along Highway 970. 1996.

a. Clark Fork River, MT.
Source: Allan Potter, Geomax.

b. Cowlitz River, near Toledo, WA.

d. Upper Klickitat River. 2001.
Source: Allen Potter, Geomax.

Figure 6-6. Various applications of log or rock barbs throughout Washington State.


LK – Length of bank key
L – Effective length of barb
S – Spacing
W – Bank full channel width
R – Radius of curvature
D_T – Distance from bank toe to thalweg
NOT TO SCALE
LK (Varies see text)
L
S
Barb spacing = 4 to 5(L) (not to scale)
Tangent line
50° to 85°
Point bar
R
Channel centerline
Original thalweg (T1)
D_{T1}
New thalweg (T2)
Revegetate disturbed areas
W
Flow
PLAN VIEW
FIGURE 6–7
BARBS
CONCEPTUAL DESIGN
INTEGRATED STREAMBANK PROTECTION GUIDELINES

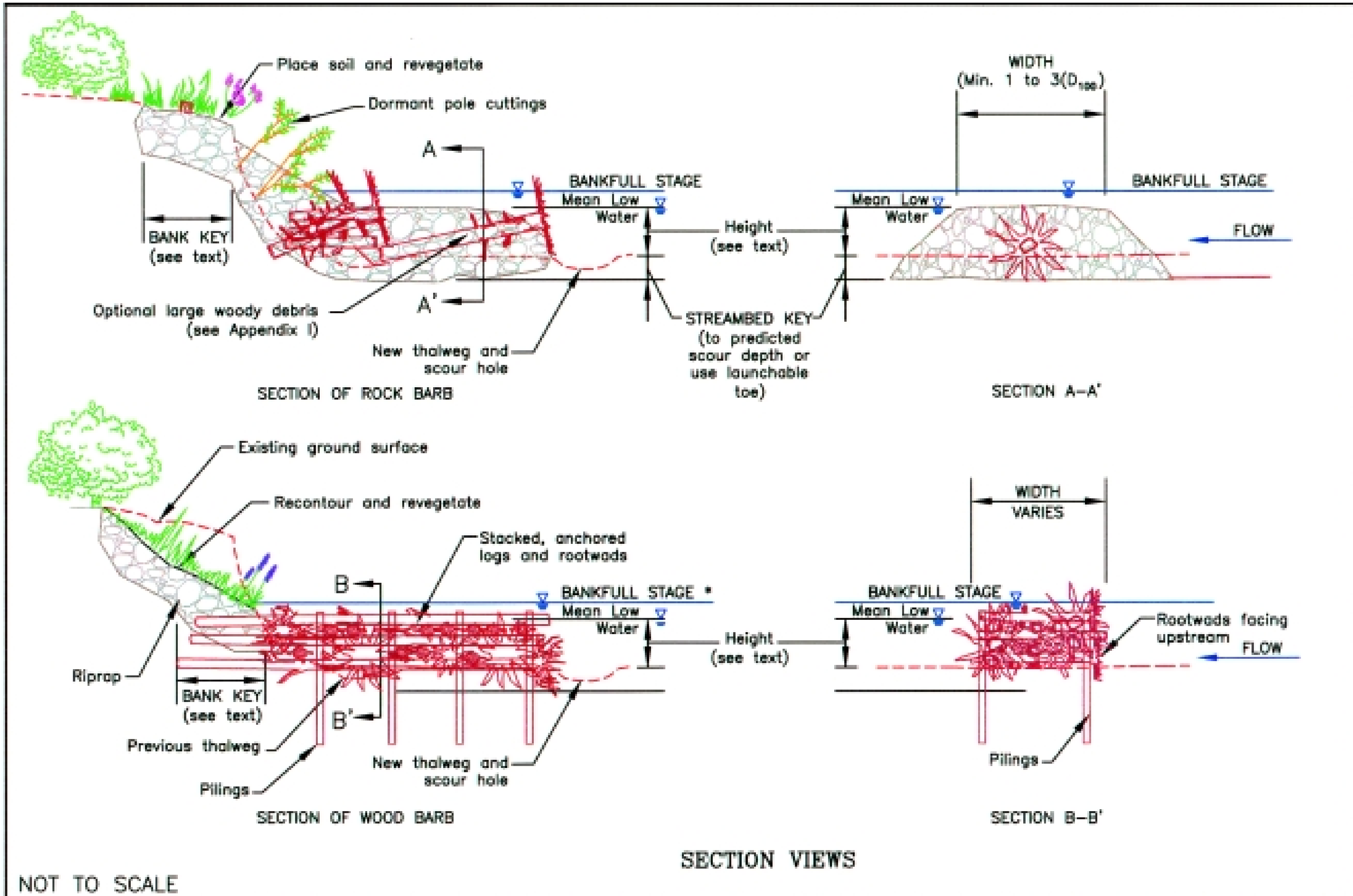


FIGURE 6–8

BARBS
CONCEPTUAL DESIGN

INTEGRATED STREAMBANK PROTECTION GUIDELINES
www.wa.gov/wdfw/hab/ahg/strmbank.htm

Engineered Log Jams
Flow-Redirection Techniques

The following technique was developed for the Integrated Streambank Protection Guideline. Its focus is on streambank protection. While similarly titled techniques may appear in other Aquatic Habitat Guidelines, their contents may differ from the text presented here.

DESCRIPTION

Engineered log jams are collections of large woody debris that redirect flow and provide stability to a streambank or downstream gravel bar. Engineered-log-jam constructions are patterned after stable, natural log jams and can be either unanchored or anchored in place using man-made materials. Naturally occurring log jams in alluvial channels are usually formed by one or several key members, consisting of large trees with rootwads attached, that stabilize and anchor other debris that is "racked" against the key members.[1] Log jams extend above bankfull water surface and, when connected to a streambank, are hydraulically similar to groins. *Figure 6-9* (at the end of this technique) shows examples of engineered log jams throughout Washington State.

Naturally occurring log jams may start as a single, large tree, as a large number of trees drifting together or as an undercut, timbered bank giving way and the trees coming with it. Over the years, people have removed many of these naturally formed structures for navigation, firewood and flood-control purposes. However, log jams provide habitat for a wide variety of fish species during most of their life stages. Engineered log jams are also fundamental to the dynamics of a healthy, forested, river ecosystems.[2] Engineered log jams as a bank-protection treatment are still considered experimental, but they are becoming increasingly popular as bank protection because they integrate fish-habitat restoration with bank protection.

APPLICATION

Prior to extensive logging activities in the past century, log jams were common throughout many of our streams. These accumulations of woody material helped create stable stream channels and habitat for fish and wildlife. Only in recent years have engineers and scientists begun studying the role of log jams in stabilizing streambanks. Mimicking how these accumulations form and function is the basis for the concept and design of engineered log jams.

Engineered log jams are used to realign a channel or redirect flow away from a streambank to protect it from erosional forces. They are also used to increase channel roughness to reduce flow velocities and shear stress along eroding banks. Large-woody-debris jams create a hydraulic shadow, a low-velocity zone for some distance downstream that allows sediment to settle out and stabilize. By locating a log jam along an eroding bank, the bank downstream of the jam becomes a deposition zone rather than an erosion zone. The deposition zone tends to become vegetated and continues to grow in volume over time.

Prior to designing and constructing an engineered log jam as a bank-protection technique, it is important to understand the existing physical characteristics and geomorphic processes present at a potential project site and along the reach (see Chapter 2, *Site Assessment* and Chapter 3, *Reach Assessment* for guidance).

Engineered log jams are best applied on long, uniform bends in alluvial channels. They are also appropriate when the mechanism of failure is toe erosion since they provide roughness and redirect erosive flows away from an eroding bank. When applied along a bend, they are apt to grow significantly as they recruit wood, so changes to the opposite bank should be expected. Engineered log jams are also useful in degrading channels for capturing and storing sediment and large woody material.[3] They can slow the rate of erosion in an equilibrium channel that is migrating laterally or where there is potential for a chute-cutoff, though they still allow for gradual meander migration. Large-woody-debris jams occur naturally at the inlet of many side channels. Jams can be assembled at the inlet of pre-existing or constructed side channels to regulate the amount of flood flow entering the side channel. This protects the banks in the side channel, prevents the side channel from capturing the main channel and protects existing spawning and rearing habitat in the side channel.

Engineered log jams may be appropriate when the mechanism of failure is scour. They should be placed upstream from the scour hole to redirect flow away from the obstacle that is creating the scour or to dissipate some of the energy that is causing the scour. They should not be placed directly in a scour hole. In tight-radius bends or other constricted reaches, they may not be very effective, and their application can further exacerbate existing erosion problems or move them upstream. Care in sizing and spacing engineered log jams is crucial to avoid creating a constriction.

In aggrading channels, engineered log jams may be appropriate, depending upon the severity of aggradation. They can be effective strategically if placed in a mildly aggrading channel where they can collect and store sediment. Their presence in such circumstances will better define the low-flow channel. Engineered log jams also recruit floating, large woody debris, which reduces the likelihood of the jam becoming buried and ineffective over time. When a channel has been disturbed and is carrying a high bedload, jams can be constructed in upstream reaches to stabilize sediment movement. Over the long term, engineered log jams reduce aggradation and erosion in the downstream reach. These jams can be placed either at the bank or in midchannel.

Engineered log jams provide excellent fish habitat by developing deep scour pools and associated tailout spawning areas, as well as complex cover. The structural complexity and hydraulic diversity associated with log jams provide ideal habitat for a variety of life stages and species of fish. For these reasons, engineered log jams receive high marks as a habitat-restoration and mitigation tool.

To learn more about the applicability of engineered log jams based on the mechanism of failure and causes of streambank erosion, review the screening matrices found in Chapter 5, *Identify and Select Solutions.*

Emergency

Engineered log jams are not appropriate for emergency situations. They cannot be constructed quickly, nor can they be assembled during high-flow events.

EFFECTS

Depending upon their size relative to the channel, the constriction caused by an engineered log jam may result in scour at the opposite bank or point bar. Engineered log jams generally produce scour adjacent to themselves. The scour at the margin of the jam and the associated downstream deposition moves the location of the thalweg away from an eroding bank. One observed effect is the tendency for a side channel to form on the back side of the jam, against the bank.[1] This is a result of the jam causing an obstruction to flows above the bankfull elevation. Jams tend to split the flow, and the flow directed along the bank may create a side channel. If side-channel development is anticipated and undesirable, extend the jam into the bank and floodplain, and anchor it to a stable location.

Engineered log jams offer a distinct advantage over most rock structures such as barbs and groins. As scour holes develop adjacent to the log jam, the interlocking nature of log jams allow them to deform and settle; effectively retaining the structural integrity of the structure.[2]

DESIGN

Conceptual design drawings of engineered log jams are shown in *Figure 6-10* and *Figure 6-11*.

Stability

The design of an engineered log jam requires a thorough analysis of channel hydraulics, which should be conducted by a qualified engineer. Engineered log jams can be designed with or without the use of anchoring hardware. Properly designed and located log jams can be very stable with life expectancies equal to or exceeding the design life of traditional bank protection techniques (e.g., groins, drop structures, revetments).[2]

Stabilizing key members (large logs with rootwads attached) can be accomplished at most flows by the ballasting effect of large logs and/or boulders.[1] Determining the necessary ballast mass requires a detailed stability analysis of fluid drag, buoyancy, lift and friction-resisting forces, and weight of the ballast logs and/or boulders.[4] A structure is stable when the sum of the resisting forces exceeds the sum of the driving forces (e.g., drag, lift and buoyancy). Hydraulic conditions often result in sediment deposition on the downstream side of a log jam. This deposition buries much of the wood and will increase the effective weight and, hence, the stability of the log jam. The process of deposition can occur naturally or be accelerated by placing excavated sediments during initial construction to bury the key members.[2]

Designing an unanchored, engineered log jam requires excavating the streambed to provide a trench for the key member(s). The depth of excavation depends on channel hydraulics, substrate characteristics, channel dimensions and the size of wood. Once a key member is placed in a trench, the trench is covered with excavated sediment to provide additional ballast and frictional resistance to drag forces. Large woody material (whole trees with rootwads attached) are stacked (stacked members) on the key members for ballast. Next, whole trees, logs and/or rootwads are racked (racked members) on the upstream side of the key-piece rootwad(s).

The number of pieces racked against the rootwad(s) depends upon the need for immediate protection, channel dimensions and hydraulics and the likelihood of recruiting additional debris.

Unanchored, engineered log jams must be dense, with racked and stacked pieces carefully interlocked. The more dense the rack, the less flow will pass through it, thereby increasing the stability of the log jam. Scour under part of a loosely assembled structure may destabilize it and allow portions to be washed away. Dense structures, on the other hand, act as a unit. They settle uniformly and hold ballast well.

Engineered log jams can be anchored with pilings (see *Figure 6-10*). In small-grained substrates, a row of log pilings can be driven vertically into the streambed using the excavator bucket. In larger substrate, pile-driving equipment may be required, as well as steel tips on the logs. The logs need to be long enough to extend below estimated scour depths. A second row of pilings should be driven into the streambed at least 20 feet downstream, and brace logs should be anchored between them. Large woody debris is then racked against the upstream side of the brace logs and the first row of pilings, just as they are for unanchored engineered log jams. The braces are needed because there is a limit to the size and, consequently, the strength of logs that can be driven with an excavator. The braces distribute the shearing force of the racked logs between the two rows of pilings. The upstream row of piles is in the area where scour will form around the log jam. The downstream row is positioned in the deposition zone, safe from the undermining effects of scour.

In cases where the substrate will not allow logs to be driven, steel pilings can be used. If they can be driven deep enough, a single row may be sufficient. The buildup of debris will eventually hide the pilings from view.

Other methods of anchoring include attaching cable to the key logs and using an adhesive (e.g., epoxy) to glue the cable to boulders for ballast. If possible, the boulders should be buried in the bed to act as deadman anchors. Another approach is to partially bury logs into the bank so that they still extend into the channel, perpendicular to the direction of flow. Logs are then racked against the upstream side of the partially buried log. Some sites may require brace logs and/or a rock toe as additional reinforcement. To learn more about how to anchor large woody debris, refer to Appendix I, *Anchoring and Placement of Large Woody Debris.*

Dimensions and Orientation

The shape of engineered log jams depends upon channel hydraulics, desired results and cost. In naturally formed jams, the most stable configuration is one where key members are oriented parallel to the high flow, with their rootwads upstream. Racked wood is generally positioned perpendicular to the flow direction. In many cases, debris collects upstream against the bank and forms a concave shape (from plan view) that is more streamlined. Using different methods of anchoring the jam may allow different shapes and alignments to form, and collection of additional wood on the engineered log jam during floods will potentially change the shape and dimensions of the jam.

The correct spacing and dimensions of jams are closely related. When positioning a series of engineered log jams along an eroding channel bend, they should begin below the cross-over riffle at the head of the bend. Spacing should be similar to that recommended for groins, but bear in mind that engineered log jams may become longer than groins as woody material is captured and collected over time. Groins are discussed as a separate technique in this chapter. The effective length (L_e) of an engineered log jam is the distance the structure extends into the channel, measured perpendicular to the bank. It does not include that portion that is keyed into the bank. Effective length must be considered when establishing spacing requirements. The furthest upstream jam in a series should be expected to grow the most as it will intercept additional floating woody material before it reaches subsequent jams. This phenomenon allows increased spacing between the first and second structures. Downstream structures may accumulate debris, but it will probably collect at a slower rate than the first jam in the series. Expect the accumulation to occur in both the upstream direction and laterally. This growth must be anticipated and may present a problem if channel constriction is an issue.

The size of materials used in the engineered log jam will depend upon the method of anchoring. The required size of pieces will be based on the calculations of drag, friction, lift and buoyancy. It's also important to take into consideration the anticipated rate of wood decomposition, wood density and the length of project life. Racked pieces do not usually function as structural members of engineered log jams, so they can be any size, particularly if accumulation of additional debris on the rack is anticipated. Determining the correct size for structural members should be accomplished by a qualified engineer.

BIOLOGICAL CONSIDERATIONS

Mitigation Requirements for the Technique

Engineered log jams provide valuable fish and wildlife habitat. Because they are so valuable to fish and wildlife, only construction impacts need to be mitigated. Immediately following placement of engineered log jams, there may be temporary, short-term impacts on spawning. Existing spawning areas may shift or scour; while others may accrete with fines while new spawning areas are forming. It may take the channel a period of time to adjust to the jams. However, the long-term habitat benefits of engineered log jams far out-weigh these short-term impacts.

Construction-related impacts do, however, require mitigation. Care should be used in gaining equipment access to the site to minimize construction impacts. Refer to Chapter 4, *Considerations for a Solution* and Matrix 3 in Chapter 5 for more detail on mitigation needs for this treatment.

Mitigation Benefits Provided by the Technique

The structural and hydraulic diversity that engineered log jams provide creates habitat for a multitude of fish species at nearly every stage of life. Engineered log jams create excellent cover, holding and rearing habitats. At the tailout from the scour hole created by an engineered log jam, spawning habitat may be created. The detritus they accumulate, particularly smaller twigs and leaves that decay rapidly, also serves as a food to some aquatic insects that fish consume.

RISK

Engineered log jams pose inherent risks to infrastructure and human stream users. These risks include:

- safety hazards caused by the log jams or the cables that anchor them (this risk can be somewhat reduced by placing warning signs upstream from the log jams to alert boaters),
- blockage of culverts or bridge openings by large woody debris that has been dislodged from a log jam upstream,
- unanticipated erosion across the channel or to the adjacent streambank,
- increased channel roughness and constriction, and/or
- increased flood stage.

Careful, well-calculated design and positioning of engineered log jams can minimize all of these risks. Refer to Matrix 3 in Chapter 5 for more detail on mitigaation benefits of this treatment.

Reliability/Uncertainty of Technique

The use of engineering log jams as a streambank-protection technique is relatively new, with little available research information to document their performance. Monitoring and performance reporting is encouraged to aid in further development of this technique by future practitioners. Appendix J, *Monitoring* provides more information on how to observe and record project performance over time.

CONSTRUCTION CONSIDERATIONS

Equipment and Materials Required

Large woody debris should be of a size (length and width) and species that can remain intact and stable for many years. Avoid using hardwood species such as alder or cottonwood, which decay rapidly. Coniferous species such as cedar, fir and pine are better choices. If sufficiently large key members are not available or can not be transported in one piece to the site, several trees could be cabled or pinned together to form a composite key member. Large and long logs imported from off-site locations may need to be cut into pieces for transport and then reassembled on site by splicing, gluing and tacking pieces back together.

Use of on-site wood resources can greatly simplify construction and reduce costs. Appropriating single logs from dry gravel bars is an option with minimal short-term impacts. Consider the density or loading of large wood in the reach before deciding to use on-site wood. If the channel is deficient of large wood, it may be necessary to import wood for the structure(s). One of the factors that will help determine whether off-site wood can and should be imported to the site is whether or not equipment can move wood of the required size and length from a distant site to the work site.

Wood buoyancy can be a problem during construction since much of the log needs to be installed below the water surface. To address this problem, the site may need to be dewatered to allow for placement and anchoring of large pieces. The use of previously saturated wood can simplify construction by reducing buoyancy problems during installation. See Appendix M, *Construction Considerations* for information about dewatering. Turbidity may also be a significant problem during installation due to the amount of digging in the channel bed required during installation. This can be avoided by dewatering the installation site, or by creating a coffer system that isolates the immediate site from flowing water.

Protection of the existing riparian zone is a high priority, particularly in drier climates where replacement of the canopy can take decades. The use of walking excavators, winches and hand labor may be required at some sites.

Timing Considerations

Construction should be conducted during a period where impacts to critical resident and anadromous fish life stages, such as spawning or migration, are avoided and when dewatering for construction is possible. Low-flow conditions are ideal for the placement of engineered log jams and may be essential for dewatering efforts. Dewatering eases installation and prevents siltation of the stream during construction. In-stream work windows vary among fish species and streams. Contact the Washington Department of Fish and Wildlife's Area Habitat Biologist for information on work windows (see Appendix B, *Washington Department of Fish and Wildlife Contact Information*). Further discussion of construction timing and dewatering can be found in Appendix M.

Cost

Costs for installing engineered log jams are site-specific and are affected primarily by availability of wood materials, dewatering capabilities and equipment access. Engineered log jams constructed in Washington State have ranged in cost between $1,800 to $80,000 to install.

Large woody debris can vary considerably in cost from virtually free (as locally salvaged wood), to quite costly (large-diameter, full-length cedar trees that may have to be sawn for transport and later re-assembled). Large woody debris can cost between a few hundred dollars to a thousand dollars per piece. Equipment costs can also be substantial, especially when specialized equipment is required, such as helicopters for wood delivery, spider hoes for access and considerable manual labor for installation. Appendix L, *Cost of Techniques* provides additional information and a case study on estimating project costs.

MAINTENANCE

Maintenance of engineered log jams includes replacement, realignment or removal of pieces following storm events equal to or greater than what they were designed to withstand. If anchored, the anchoring hardware may also need to be readjusted or replaced. Any biotechnical bank protection between the log jams will also need maintenance.

MONITORING

Monitoring engineered jams should determine if the structures are performing in accordance with design flow criteria and whether they are providing the habitat and bank protection desired. Because large-woody-debris projects generally involve impacts to the channel and banks, they will require comprehensive monitoring of both channel and bank features, with particular attention to habitat monitoring. For a comprehensive review of habitat-monitoring protocols, refer to Johnson, et al.[5] Habitat-monitoring protocols will likely require a monitoring schedule that is more comprehensive than that required for the integrity of the structure.

Monitoring to evaluate structural integrity should be conducted annually and following any flow events that meet or exceed design flow events. This can be accomplished by surveying precise locations of key members relative to a stationary point on shore by determining whether the jam has lost key members and by conducting a visual inspection of anchoring systems.

Details on how to develop a monitoring plan can be found in Appendix J.

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a. Cyspus River. 2001.

c. Nooksack River. 2001.

b. Tucannon River. 2001.

d. Stillaguamish River. 1998.
Source: Tim Abbe, Phillip Williams and Associates.

Figure 6-9. Examples of engineered log jams throughout Washington State.

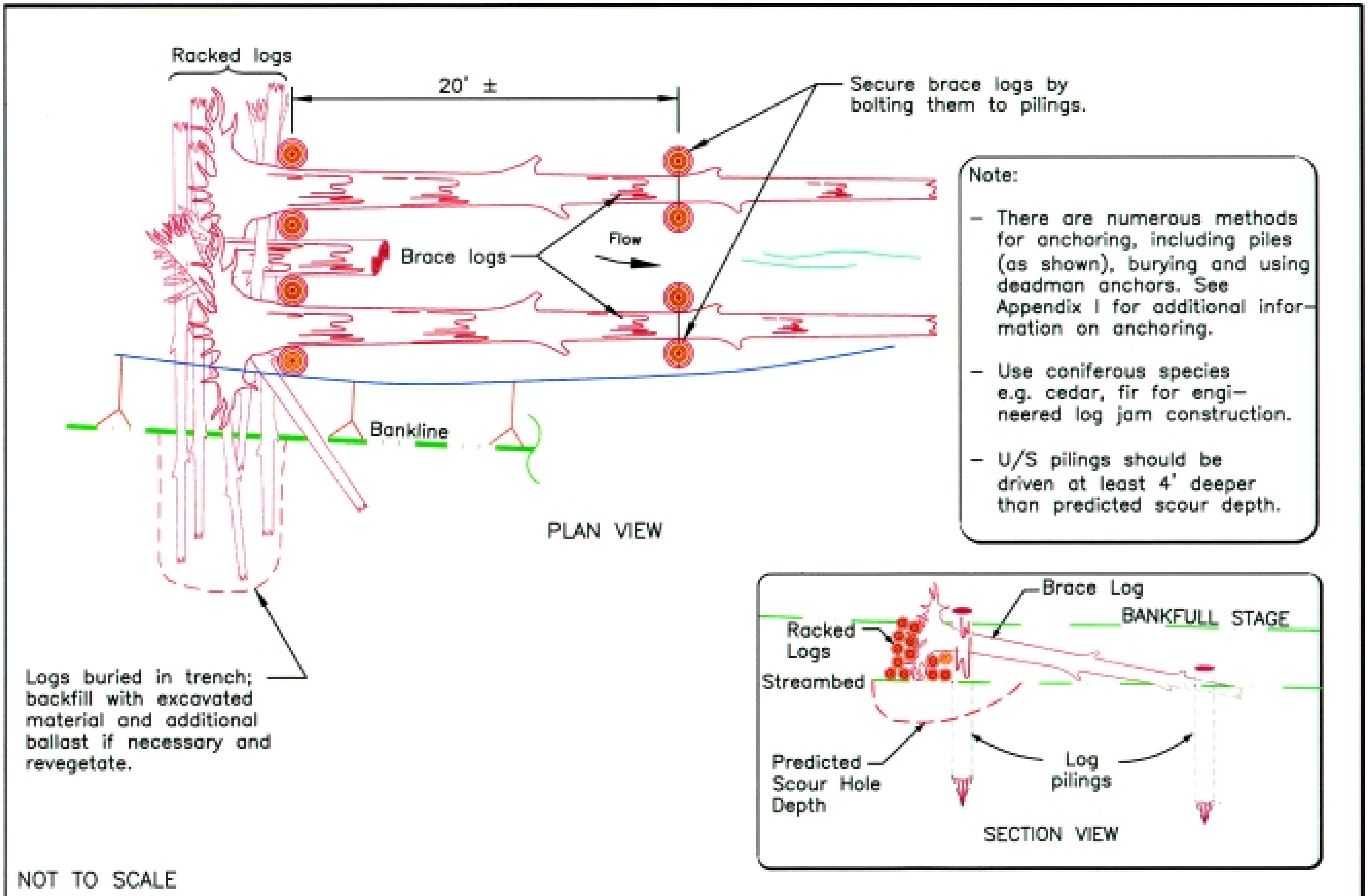
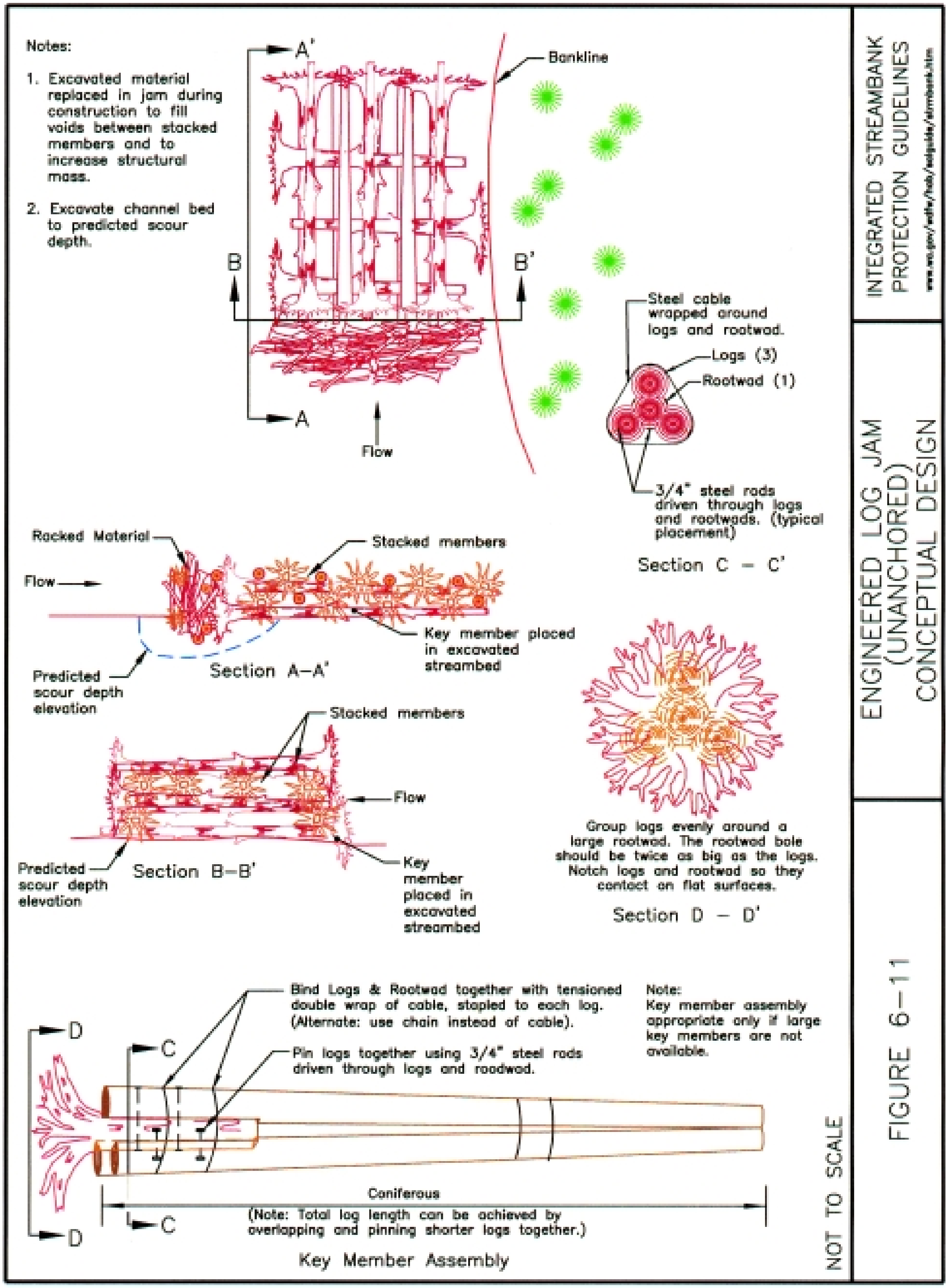


FIGURE 6–10

ENGINEERED LOG JAMS (ANCHORED) CONCEPTUAL DESIGN

INTEGRATED STREAMBANK PROTECTION GUIDELINES
www.wa.gov/wdfw/hab/salguide/strmbank.htm


Notes:
1. Excavated material replaced in jam during construction to fill voids between stacked members and to increase structural mass.
2. Excavate channel bed to predicted scour depth.
A'
A
B
B'
Bankline
Flow
Steel cable wrapped around logs and rootwad.
Logs (3)
Rootwad (1)
3/4" steel rods driven through logs and rootwads. (typical placement)
Section C – C'
Rocked Material
Stacked members
Flow
Key member placed in excavated streambed
Predicted scour depth elevation
Section A–A'
Stacked members
Flow
Predicted scour depth elevation
Section B–B'
Key member placed in excavated streambed
Group logs evenly around a large rootwad. The rootwad bole should be twice as big as the logs. Notch logs and rootwad so they contact on flat surfaces.
Section D – D'
Bind Logs & Rootwad together with tensioned double wrap of cable, stapled to each log. (Alternate: use chain instead of cable).
Pin logs together using 3/4" steel rods driven through logs and roodwad.
Note:
Key member assembly appropriate only if large key members are not available.
D
C
C
D
Coniferous
(Note: Total log length can be achieved by overlapping and pinning shorter logs together.)
Key Member Assembly
NOT TO SCALE
INTEGRATED STREAMBANK PROTECTION GUIDELINES
ENGINEERED LOG JAM (UNANCHORED) CONCEPTUAL DESIGN
FIGURE 6–11

DESCRIPTION

Drop structures are low-elevation weirs that span the entire width of the channel. They are designed to spill and direct flow away from an eroding bank, dissipate and redistribute energy and provide grade stabilization. Drop structures are similar to porous weirs; however, because they are not as porous, they create substantially more backwater than porous weirs. *Figure 6-12* (at the end of this technique discussion) shows various applications of drop structures throughout Washington State.

Drop structures are typically constructed with rock or logs, though sheet pile and concrete are also used. Log and rock drop structures have been used extensively in Washington State to stabilize channel grades, to backwater culverts and to provide bank protection (primarily in fish passage and habitat-restoration projects).

APPLICATION

Applications for drop structures include grade control in degrading reaches, flow realignment, fish passage, channel diversity (pool habitat) and energy dissipation. They are most applicable in channels that have slopes of up to about three percent. The Washington Department of Fish and Wildlife has constructed log drop structures for the purposes of reducing channel slope and improving fish passage, especially through culverts.

It is important to determine whether drop structures are the appropriate solution for the particular mechanism of failure and causes of bank erosion in question (see Chapter 2, *Site Assessment* and Chapter 3, *Reach Assessment* for guidance). Drop structures are commonly used in degrading channels to restore the channel bed to a more stable profile and elevation. They can also act as grade-control structures by preventing a nickpoint from migrating upstream. Drop structures are inappropriate in aggrading reaches. Aggrading reaches will deposit sediment around and over the drop structure, thereby counteracting their intended function. They should also be avoided where there is the potential for an avulsion. See the screening matrices in Chapter 5, *Identify and Select Solutions* for more guidance on determining the applicability of drop structures based on the mechanism of failure and causes of streambank erosion.

Variations

Drop structures are typically constructed in a symmetric, upstream-pointed chevron or arch configuration. Drop structures have also commonly been installed as straight features across the channel, though they tend to flatten the channel cross section and eliminate diversity in the channel. Straight drop structures are, therefore, not recommended from a habitat-diversity perspective. On the other hand, drop structures that are configured in S-patterns or other asymmetrical layouts across the channel can simulate natural shelves and drops on the channel bed, potentially enhancing habitat diversity.

Deformable Drop Structures

Over time, the length (measured from the upstream edge to the downstream edge) of the drop structure may narrow as rocks fall into scoured holes. Eventually, the components of the structure will become more tightly packed together; however, this will not compromise the structure's strength. Structural stability is provided through careful selection and placement of boulders across the channel. Fractured rock is often necessary to lock the structure together. Arches can only be effective across relatively narrow channels, usually less than 20 feet. The expectation is that the arch may eventually break apart, and the boulders will spread out to form a cluster. This is expected to occur gradually as the bank and bed are stabilized by vegetation and debris. The cluster of boulders remains to form a cascade; an outcome similar to that expected for a porous weir rather than a distinct drop structure.

Emergency

Drop structures are not useful in emergency streambank protection. They completely span the stream channel and usually require construction from within the channel, which may not be possible during an emergency situation. However, on smaller channels that are actively degrading or headcutting, rock may be placed as a grade-control measure during emergency conditions to arrest formation or progression of a nickpoint.

EFFECTS

Drop structures increase backwater conditions by raising the effective bed elevation. This commonly induces sediment deposition and increases the water stage upstream of the structure at a variety of flows. Elevated stage may be a concern for channels within flood-regulated jurisdictions. Deposition upstream of a drop structure is particularly common in moderate to high bedload channels. In degrading channels, upstream backwater effects are not as likely due to minimal sediment availability. In these channels, bank erosion and flooding upstream may decrease. However, downstream effects from scour may create a fish passage barrier. Additionally, a fish barrier may result if the upstream-to-downstream difference in water-surface elevation is excessive.

Even with their potential risk of creating fish barriers, an important benefit of drop structures is the habitat they can provide. They create turbulence cover and a diversity of plunge pools, eddies and velocity chutes. They also catch debris, provide aeration and collect and sort gravel in the tailout for spawning habitat. Realigning the thalweg away from a downstream eroding bank will reduce the depth of near-bank pools; however, loss in pool habitat may be compensated by the plunge-pool habitat created by the drop structure.

Depending upon its shape, the structure may affect the channel cross section. Drop structures that are flat and straight across the channel tend to create a channel cross section that is flat and uniform. The pool created in this case is at the base of the structure and spans the entire channel. Drop structures that have a "V" cross section geometry create a thalweg in the pool and generate more diversity. The pool is longer but narrower and may not span the channel.

DESIGN

Conceptual design drawings are shown in *Figure 6-13* and *Figure 6-14*

Dimensions

The width of the drop structure spans the entire bankfull width of the channel. Straight structures are not recommended. Structures configured as a chevron (shaped like a "V") can be symmetrical or asymmetrical, depending upon the thalweg alignment as it approaches the structure and the desired thalweg alignment immediately downstream. Generally, each leg of the "V" will span to the thalweg. Drop structures have been installed in channels up to 400 feet wide. Drop-structure *length*, or the distance between the upstream and downstream ends, is typically designed to be less than 15 feet to accommodate equipment access and to protect the structure's stability.

The upstream water stage, allowable head differential and desired hydraulics dictate the height of the drop structure, measured at the apex of the arch or chevron. If designing multiple drop structures, the height of the structures should be such that the low-flow head differential from one structure to the next is no more than one foot. The head differential criterion is necessary to ensure fish passage and varies based on passage needs of specific species. If designing a single drop structure, the height is normally set at low-flow water stage while maintaining less than one foot of head differential through the structure.

The allowable head differential of one foot must be satisfied at all flows between the low- and high-flow fish-passage design criteria. The low-flow criterion is the two-year, seven-day, low-flow discharge or 95-percent exceedance flow during the migration months for the species of concern. The high-flow criterion is the flow that is not exceeded for more than 10 percent of the time during the months of adult fish passage. The two-year flood flow may be used as the high-flow when stream-discharge data is unavailable. Note that the one-foot head differential applies for passage of adult chinook, coho, sockeye and steelhead. Adult trout (greater than six inches), and pink and chum salmon have an allowable head differential of 0.8 feet. If upstream juvenile fish passage is critical, the drop should not exceed six inches.

Orientation

Drop structures are typically placed in an upstream pointing arch or chevron configuration, or in a straight line across the channel (roughly perpendicular to the flow). If chevron shaped, the alignment of each leg is angled at approximately 45 degrees from the approaching stream flow. If the chevron-shaped drop structure consists of rock, it may eventually evolve into more of a parabolic shape. A chevron-shaped drop structure is hydraulically very similar to a barb; it is basically two barbs that extend from opposite banks toward one another and connect at the thalweg.

When applied in a degraded channel, the height of a drop structure (or a series of drop structures) is set to raise the channel-bed elevation and restore the desired water-surface profile. Care is needed in this case to ensure downstream degradation is not exacerbated. The sediment-storage capacity of a drop structure can be enough to instigate additional degradation downstream. This is especially true if the initial degradation is due to a decrease in sediment supply. Drop-structure spacing is based on the desired channel gradient and angle of flow leaving the structure. The Washington Department of Fish and Wildlife recommends the use of chevron-type drop structures within streams having maximum gradients of three percent and straight-weir-type drop structures in streams having up to five-percent gradients. Chevron weirs concentrate flow energy at the thalweg. Straight weirs spread the energy across the channel and are therefore more efficient at energy dissipation, which allows them to be placed in steeper streams.

Configuration

The drop structure should slope from the banks toward the apex. Generally, the horizontal-to-vertical ratio for this slope should not exceed 5:1. At the bankline, the top of the structure should not exceed the elevation of the channel-forming flow. A notch is often placed in the structure so that boaters and/or fish can pass through during low-flow stages. The length of the legs on a V-shaped structure can vary; and, therefore, the location of the apex varies across the channel. A meandering thalweg and additional channel complexity should be taken into account in positioning the apex. Typically, the apex is located within the center third of the channel. Landward of the bankline, the drop structure should be keyed into the bank to provide scour protection from overbank flow spilling back into the channel. The key will extend from the bankline into the bank at a slope of 1.5:1 to 2:1. A minimum length for a rock drop structure bank key is four times the D_{100} diameter of the header rocks.[1] For sizing of rocks, refer to the technique descriptions in this chapter for *Riprap* and *Porous Weirs*. A minimum length for a log drop structure bank key is a minimum of five feet into the bank.

Large woody debris can be incorporated into the drop structure for added habitat benefit, additional roughness and flow realignment. Such material can be incorporated near the bankline by anchoring a tree trunk with attached rootwad into the drop structure. The tree trunk should run parallel to the bankline. Care must be taken when installing large woody debris since it may also create a constriction and additional backwater. Please refer to Appendix I, *Anchoring and Placement of Large Woody Debris* for further guidance.

It is also important to minimize bank disturbance and vegetation removal during construction. Buried cut-off logs or rocks can be incorporated into the bank key. Buried logs or rocks should be oriented perpendicular to the overbank flows. Revegetating the bank at both keys is necessary for added structural strength and habitat needs. The bank may need to be protected for a short distance upstream and downstream of the key. Large woody debris and/or rock can be placed along the bank as launchable material (see the technique description in this chapter on *Riprap*, for more information about launchable rock). Placement of large woody debris and/or rock at this critical location will help to prevent erosion, which could otherwise result in flanking of the drop structure at high flows.

BIOLOGICAL CONSIDERATIONS

Mitigation Requirements for the Technique

Placement of drop structures in the channel will fix the bed profile and prompt adjustments in the thalweg alignment. Existing spawning areas may be impacted by new scour patterns that result from these channel modifications. Natural channel evolution, including dynamic erosional and depositional processes, will be reduced. This represents a lost opportunity for future development of habitat complexity resulting from periodic inputs of gravel and woody debris. Habitat losses can be mitigated to some extent by incorporating woody debris into the design of drop structures, as previously mentioned.

The depth of downstream pools adjacent to eroding banks will likely be reduced by redirection of the thalweg away from the eroding bank unless the structure is specifically designed to maintain or create those pools. These near-bank pools provide some of the best types of rearing habitat, especially when there is wood in them and cover from the overhanging bank. Loss of near-bank pool habitat can be mitigated by creating scour pools and placing large woody debris on the downstream side of the drop structure.

The construction of rigid, nondeformable structures such as embedded rock-and-log drop structures requires excavation into the streambed. Construction typically requires significant channel disturbance, which must be mitigated with sediment control and dewatering. Deformable structures are often built on the existing streambed and may therefore not require dewatering. Refer to Chapter 4, *Considerations for a Solution* and Matrix 3 in Chapter 5 for more detail on mitigation needs for this bank treatment.

Mitigation Benefits Provided by the Technique

Surface turbulence will create hiding cover for juvenile fish. The structure will also provide interstitial hiding areas, particularly near the bank. During high flow, the turbulence may prevent the structure from being very useful as flood refuge for fish. If the required head differential between the low- and high-flow fish-passage design flows is met, fish passage will not be a problem. If there is excess head spilling over the drop structure, adult chum salmon and juvenile salmonids may be prevented from passing upstream.

Drop structures may provide habitat complexity by breaking up a long glide or riffle into different gradients. They also sort and capture spawning-sized gravel in the tailout downstream from the scour holes. Refer to Matrix 3 in Chapter 5 for more detail on the mitigation benefits of this bank treatment.

RISK

Habitat

Drop structures will cause the bed and thalweg to shift and the banks to accrete. Depending upon the channel size, bedload movement and particle size, it may take time for the channel to adjust to this structure. In the adjustment period, spawning areas may scour or accrete, and any eggs or alevins in the bed could be damaged. Relative to other habitat-enhancement options, drop structures tend to provide very uniform habitat features with little diversity if placed in a series.

Infrastructure

The risk to infrastructure situated on the streambanks is relatively low. Drop structures tend to focus stream energy towards the center of the channel and away from the banks. If drop structures are improperly designed and/or constructed, however, the excessive backwater they may create can place upstream property and structures at risk. Drop structures that are constructed too high across the channel or that lack proper sloping toward the channel center can cause increased erosion at the bank key, which may result in flanking of the structure.

Reliability/Uncertainty of Technique

Many rock and log drop structures installed more than 20 years ago continue to function well. If constructed properly and maintained well, it is reasonable to expect that drop structures will serve their designated purpose for many years.

CONSTRUCTION CONSIDERATIONS

Materials Required

Drop structures that are made of rock should use rock that is sound, dense, and free from cracks, seams and other defects that would tend to increase its deterioration from weathering, freezing and thawing, or other natural causes. Angular rock is preferred over rounded rock for its ability to lock tightly together. Rock that resembles native material should be selected when possible.

Drop structures can also be constructed using logs. The type of wood selected may be important if longevity of the bank protection is a concern. Avoid using species that decay rapidly, such as alder or cottonwood. Coniferous species such as cedar, fir and pine are better choices.

Other materials necessary for a drop structure includes filter material (fabric and/or backfill), concrete block and riprap for ballasting and anchoring (for log drop structure), rebar, and large woody debris for mitigation and habitat components. For further discussion of filter materials and large woody debris, refer to Appendix H, *Planting Considerations and Erosion-Control Fabrics* and Appendix I.

Timing Considerations

Drop structures should be constructed during low-flow conditions to minimize instream disturbance. It is typically necessary to work within the stream channel to construct drop structures, which means it may be necessary to dewater the channel. Dewatering can be accomplished using coffer dams to isolate the channel during construction. Instream work windows vary among fish species and streams. Contact the Washington Department of Fish and Wildlife's Area Habitat Biologist for information on work windows (see Appendix B, *Washington Department of Fish and Wildlife Contact Information*). Further discussion of construction timing and dewatering can also be found in Appendix M, *Construction Considerations.*

Cost

Drop structures can be a relatively low-cost approach to reducing erosive energy along a streambank. The greatest cost factor is the size of the channel. Drop structures cost approximately $75 to $200 per linear foot. The cost will be determined primarily by the cost of rock available, equipment and operator rates. Rock materials typically range in cost from $25 to $80 per cubic yard. However, dewatering, if required, will greatly increase the cost of the treatment. Additionally, access for large equipment may require that either a temporary access road be constructed, or that specialized equipment such as a spider hoe and tracked dump trucks be used to cross riparian areas for channel access and materials delivery. Refer to Appendix L, *Cost of Techniques* for further discussion of materials costs and construction costs.

MAINTENANCE

Maintenance may include replacement of rocks that shift or are dislodged by extreme flows. Replacement of rocks, logs or vegetation may also be necessary at the bank key-in points after overbank flow events.

MONITORING

Because drop-structure projects involve impacts to both the channel and the banks, the integrity of the structure itself, the channel and bank features and habitat will all need comprehensive monitoring. Monitoring of drop-structure projects should be initiated prior to construction and should include a baseline-conditions survey of the physical channel, its banks and its habitat value. This should include, at a minimum, surveys of five cross sections at intervals equal to the channel width upstream, five cross sections downstream and one cross section at the location of the drop structure. This will allow comparison of modified conditions to preproject conditions. Additionally, monitoring should include detailed as-built surveying and photo documentation from fixed photo points of the project area and the upstream and downstream reaches to allow for evaluation of performance relative to design. Details on development of a monitoring plan are discussed in Appendix J, *Monitoring.*

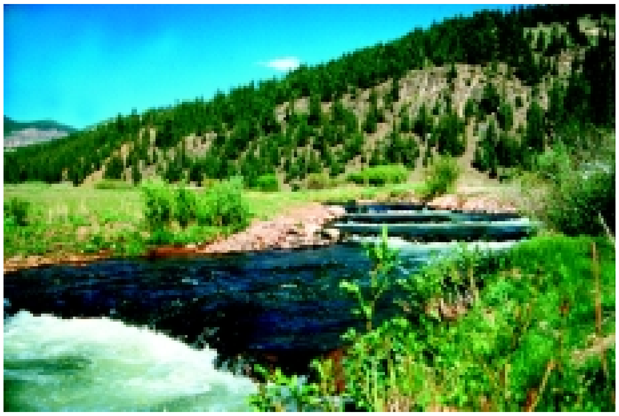
Monitoring drop structures should include preproject surveys and annual surveys thereafter of key members, and visual assessments of their configuration, dimensions and hydraulic function. A general, qualitative description of the drop structure should also be recorded and may include such observations as the general effect on channel flow characteristics and a visual description of the drop structure. The general integrity of the drop structure should be evaluated, including the identification of any significant settling of header or footer rocks as determined from survey and comparison of photos.

Impacts to the channel and to habitat must be carefully monitored. Channel changes occurring following installation can be documented by reviewing annually any cross sections that were surveyed prior to installation and at the time of completion. Patterns of sediment deposition or scour should be noted. Changes to available habitat also should be documented on a schedule conforming with fish life cycles. For a comprehensive review of habitat-monitoring protocols, refer to Johnson, et al.[2] Habitat-monitoring protocols will likely require a monitoring schedule that is more comprehensive than that required for the integrity of the structure.

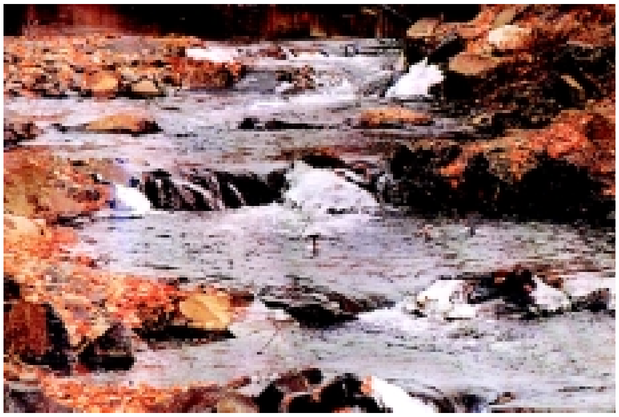
REFERENCES

1 U. S. Department of Agriculture, Natural Resources Conservation Service. 2000. Design of Rock Weirs. Technical Notes, Engineering - No. 24. Portland, OR

2 Johnson, D. H., N. Pittman, E. Wilder, J. A. Silver, R. W. Plotnikoff, B. C. Mason, K. K. Jones, P. Roger, T. A. O'Neil and C. Barrett. 2001. Inventory and Monitoring of Salmon Habitat in the Pacific Northwest - Directory and Synthesis of Protocols for Management/Research and Volunteers in Washington, Oregon, Idaho, Montana, and British Columbia. Washington Department of Fish and Wildlife, Olympia, WA.



a. Rock Drop Structures. Bellows Creek, CO. 2000. Source: Inter-Fluve, Inc.

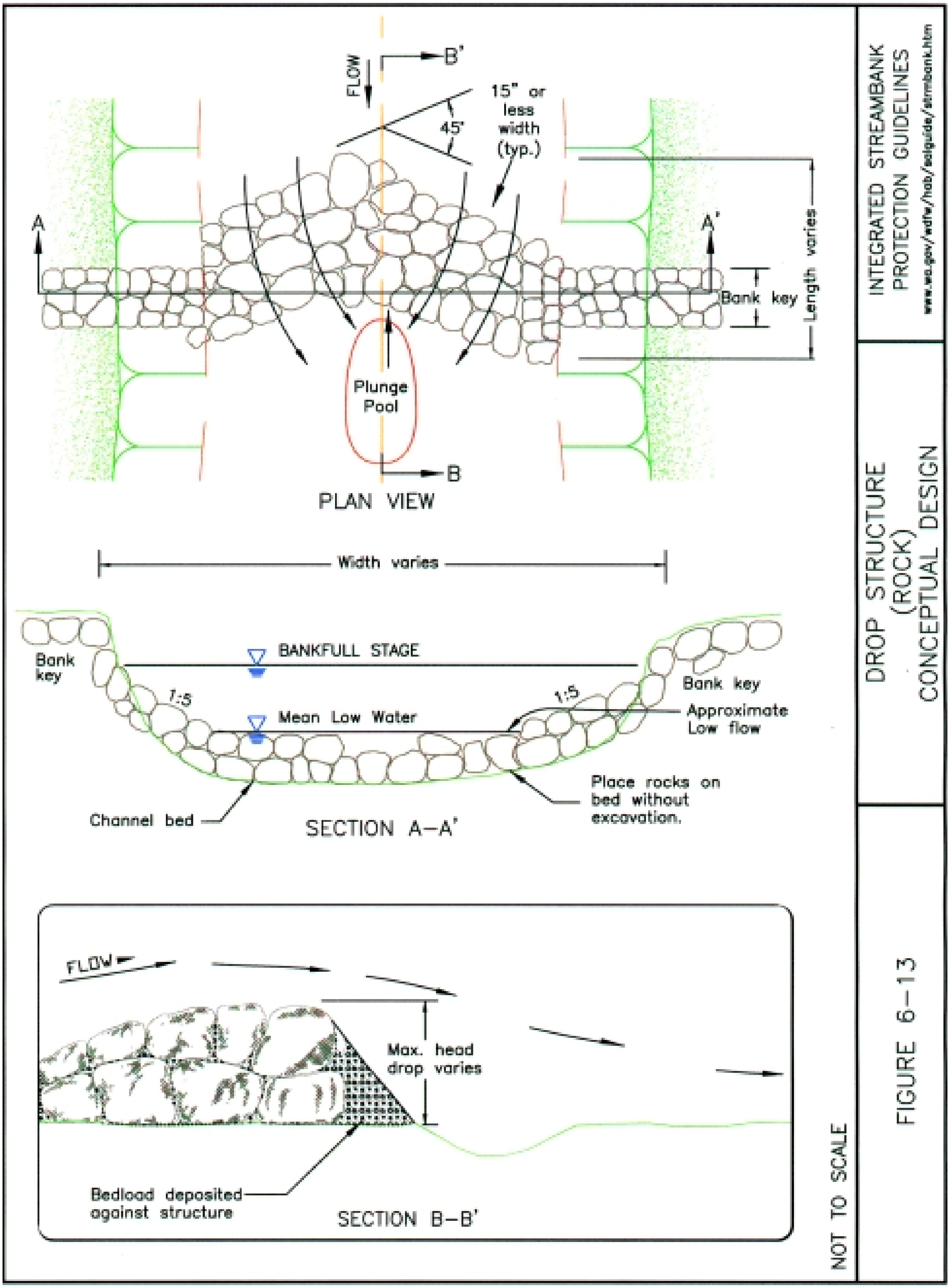


b. Rock Drop Structures. Taneum Creek, Tributary to Yakima River. 2001. Source: Allan Potter, Geomax.

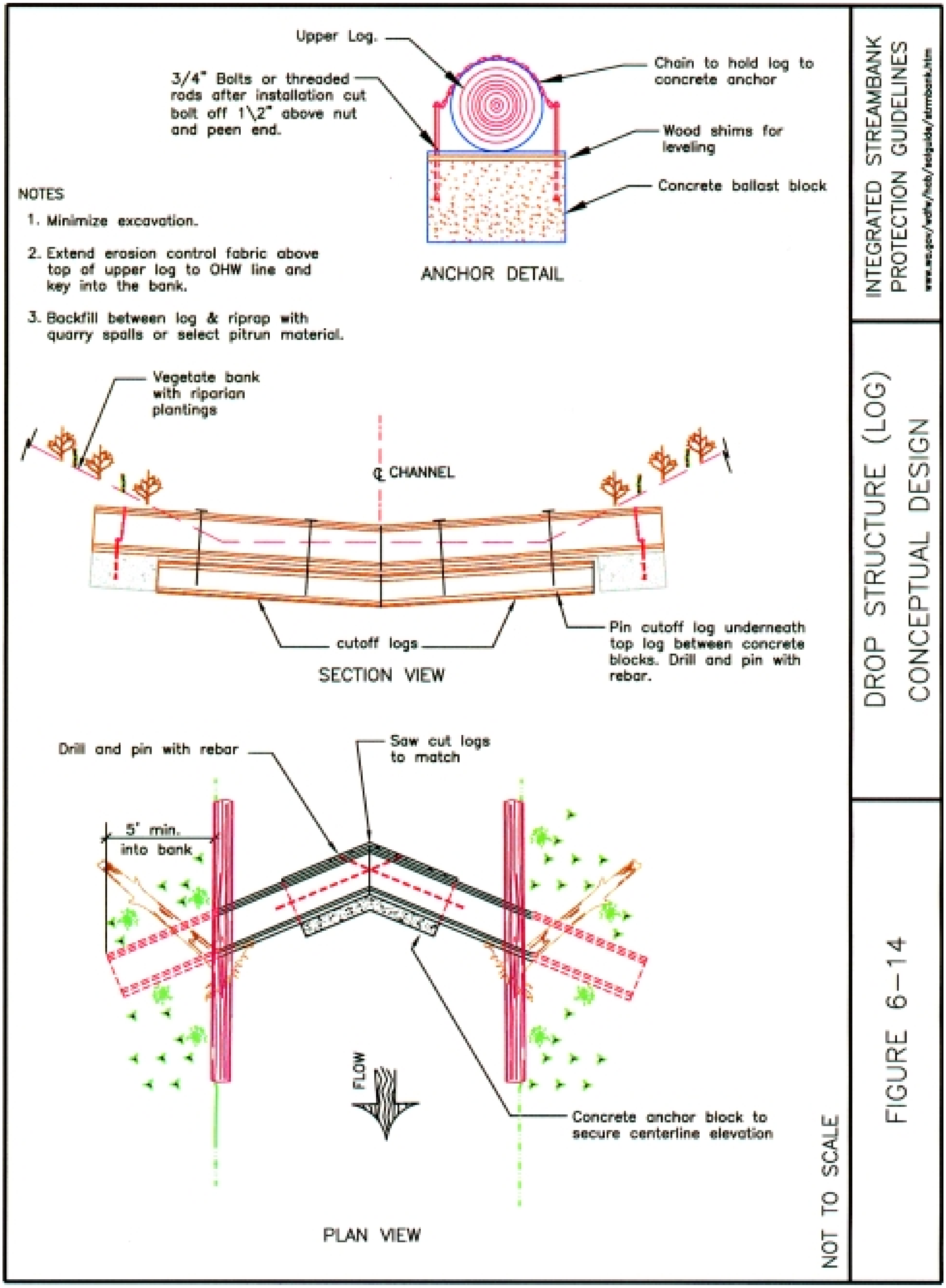
c. Vee Log Drop Structure. Little Hoko River, Tributary to Strait of Juan De Fuca. 1996.

d. Vee Log Drop Structure.

Figure 6-12. Various applications of drop structures throughout Washington State.



FLOW
B'
15" or less width (typ.)
45°
A
A'
Bank key
Length varies
Plunge Pool
B
PLAN VIEW
Width varies
BANKFULL STAGE
Bank key
1:5
1:5
Bank key
Mean Low Water
Approximate Low flow
Place rocks on bed without excavation.
Channel bed
SECTION A-A'
FLOW
Max. head drop varies
Bedload deposited against structure
SECTION B-B'
NOT TO SCALE
INTEGRATED STREAMBANK PROTECTION GUIDELINES
DROP STRUCTURE (ROCK) CONCEPTUAL DESIGN
FIGURE 6-13


Upper Log.
3/4" Bolts or threaded rods after installation cut bolt off 1\2" above nut and peen end.
Chain to hold log to concrete anchor
Wood shims for leveling
Concrete ballast block
ANCHOR DETAIL
NOTES
1. Minimize excavation.
2. Extend erosion control fabric above top of upper log to OHW line and key into the bank.
3. Backfill between log & riprap with quarry spalls or select pitrun material.
Vegetate bank with riparian plantings
℄ CHANNEL
cutoff logs
Pin cutoff log underneath top log between concrete blocks. Drill and pin with rebar.
SECTION VIEW
Drill and pin with rebar
Saw cut logs to match
5' min. into bank
FLOW
Concrete anchor block to secure centerline elevation
PLAN VIEW
NOT TO SCALE
INTEGRATED STREAMBANK PROTECTION GUIDELINES
DROP STRUCTURE (LOG) CONCEPTUAL DESIGN
FIGURE 6–14

DESCRIPTION

Porous weirs, also called vortex rock weirs,[1] are low-profile structures consisting of loosely arranged boulders that span the width of the channel. They are used to protect streambanks by redirecting the flow away from the bank and toward the center of the channel. This technique also provides energy dissipation and promotes increased sedimentation along streambanks. Scour holes and pool habitat are created by flow passing through the openings in the weir structure, which, in turn, accommodates fish passage. *Figure 6-15* (at the end of this technique discussion) shows an example of porous weirs.

APPLICATION

Porous weirs have been installed primarily in high-bedload streams and channel-reconstruction projects for bank protection. They can also be used to control the grade of the channel bed in small streams and to provide fish passage. They are most effective in gravel- and cobble-bed streams with slopes less than three percent.

Porous weirs are similar to drop structures in that they span the entire width of the channel and are used to redirect flow away from the banks. Unlike porous weirs, however, drop structures are continuous, solid structures without gaps or openings. Porous weirs, by design, have spaces between the boulders to allow fish and sediment to pass through and to enhance channel complexity. Porous weirs are deformable, whereas drop structures are rigid. The principal purpose of a drop structure is to control channel-bed grade, while porous weirs are used primarily for flow redirection and to provide channel roughness.

It is important to determine whether porous weirs are the appropriate solutions for the particular mechanism of failure and causes of bank erosion in question (see Chapter 2, *Site Assessment* and Chapter 3, *Reach Assessment* for guidance). Porous weirs are appropriate for sites where the mechanism of failure is toe erosion. Their ability to provide grade control and bed roughness also make them useful in degrading channels. Porous weirs are unsuitable for use in aggrading or high-gradient channels. They should also be avoided where there is the potential for an avulsion. Porous weirs are typically installed in conjunction with bank-protection treatments. See the screening matrices in Chapter 5, *Identify and Select Solutions*, for additional guidance on the applicability of porous weirs based on mechanism and causes of streambank erosion.

Thalweg Alignment

Porous weirs redirect erosive velocities away from the bank to the center of the stream. They can also be used as a component of a larger streambank-protection project. The weir can add to the integrity of downstream bank-protection practices by realigning the low-flow channel.

Sediment Transport

Porous weirs, if designed correctly, increase the sediment-transport capacity at the site. This is accomplished not only by making the spaces between header rocks wide enough to allow sediment to pass through, but also by mobilizing the sediment itself. Porous weirs accelerate stream flows, increasing shear stress at the bed, which leads to increases in the channel's ability to pick up and transport bedload at the site. Sustained sediment transport will help maintain or develop a low width-to-depth ratio at the site. Porous weirs typically do not affect sediment transport throughout the reach, however. Properly constructed, they have a low profile across the channel bed, which minimizes backwater conditions; and channel-forming flow events (about a 1.5-year to 5-year flood event) should be able to overtop them.

Bed Roughness

While porous weirs do a reasonable job of providing bed roughness, other techniques, such as random placement of boulders and large woody debris in the channel, might complement them and should be considered.

Grade Control

Porous weirs may act as grade-control structures in small streams when the rock is large enough that it won't become dislodged during high flows. Porous weirs should not be expected to provide grade control in larger rivers or steep channels that have the capacity to mobilize boulders (steeper than a two-percent grade).

Fish Passage

Porous weirs can be used to provide passage for fish through steep reaches, or a series of weirs can replace fish barrier drops.

Emergency

Porous weirs are not good candidates for emergency streambank protection. They completely span the stream channel and usually require construction from within the channel, which may not be possible during an emergency situation.

EFFECTS

Porous weirs redirect flow toward the channel center and away from the banks. This change in the flow direction may have both desired and undesired impacts to adjacent channel segments. For further discussion of the potential impacts of thalweg redirection, refer to Appendix F, *Fluvial Geomorphology*.

Because porous weirs constrict flows in a channel segment, they create two hydraulic conditions: 1) accelerated flow through the weir, and 2) backwater upstream of the weir. Accelerated flows may create scour between and around boulders and lead to increased sediment transport at the weir. This may result in deposition immediately downstream of the weir and formation of tailouts. Additionally, backwater upstream of the weir will exhibit reduced velocities and greater depths at a variety of flows. This may result in deposition upstream of the weir.

DESIGN

Conceptual design drawings of porous weirs are shown in *Figure 6-16*.

Dimensions

A porous weir spans the entire width of the channel and usually has a "V" shape pointing upstream. Each leg of the "V" can have either equal or different lengths, depending upon the thalweg alignment as it approaches the weir and the desired thalweg alignment immediately downstream.

In order to allow bedload to move through the weir with minimal restriction, the weir should not be placed higher than 15 percent of bankfull stage height. This height is measured at the thalweg from the top of the footer rock to the top of header rock. The height of the weir should be kept to a height that results in only nominal backwater conditions. Excessive height can cause structural failure, trigger upstream bank erosion and create a barrier to fish passage. To allow passage for the weaker swimming fish, such as chum salmon or juvenile salmonids, the difference in water-surface elevations above and below the weir should not exceed 0.8 feet. It is possible to place a notch at the weir's apex to accommodate boat and fish passage. If upstream juvenile fish passage is critical, the drop should not exceed six inches.

Rock Size

The smallest rock size used in a weir should be greater than one-third the size of the largest rock. Material sizing should follow standard riprap-sizing criteria for turbulent flow (refer to the discussion in this chapter addressing the technique, *Riprap*), with rocks that will remain immobile during the selected design flow (a minimum of a 20-year flow is recommended). The largest rocks should be used in the exposed weir section. Do not use the Isbash Curve when sizing rock for rock weirs; it will result in sizes too small for this application.

Orientation

The legs of the weir should be pointed upstream at an angle between 30 and 40 degrees. If the channel's bankfull width is greater than 40 feet, D. Rosgen recommends weirs that are shaped as a "W" (pointing upstream).[1]

The crest of the weir slopes from the bank down to the header rock in the thalweg such that the boulders nearest the bank are the last to be submerged as stage increases. The weir is completely submerged at bankfull depth.

Location

Porous weirs should be located immediately upstream from, or directly adjacent to, an eroding bank, preferably at the crossover-riffle section. The location of the weir should be near the head of a riffle to supplement and steepen the riffle. However, care must be applied when siting a weir at the crossover riffle. The crossover riffle distributes flow across the channel and, to some degree, protects the downstream bank. By siting a weir at the crossover riffle, flow will be concentrated and not distributed across the channel. This may exacerbate downstream erosion. Furthermore, location at the head of a riffle increases the riffle slope and decreases the slope upstream of the riffle.

Porous weirs are typically used in a series if the intended purpose is fish passage or grade control with an elevation change between weirs of less than one foot. For fish passage, spacing depends upon the channel slope, length of backwater and length of thalweg created downstream. For grade control, porous weirs should be placed no closer than the net drop divided by the channel slope. The net drop is measured between similar channel features (e.g., between channel-bed elevations above and below the drop, or between water-surface elevations above and below the drop). As an example, a one-foot-high weir in a stream with a two-percent gradient will have a minimum spacing of 50 feet (1.0/0.02). Studies indicate that natural pool-riffle spacing varies between three and 10 channel widths and average about six channel widths.[2]

Configuration

Footer rocks are the foundation that stabilizes the weir. They are placed below header rocks to anchor the overriding header rocks, to reduce scour and to protect the structure from possible undermining. The top of the footer rocks becomes the new bed elevation. Footer rocks need to be placed firmly into the channel bed. The depth of embedment should be approximately equal to the D_{100}.[3]

Header rocks are placed on top of footer rocks. Header rocks at each bankline are placed such that the top of the rock corresponds with bankfull stage. The gap between header rocks is 0.25 to 0.5 of the rock diameter. Too large a gap will reduce velocities needed to move bedload and dissipate energy. Too small a gap will trap sediment and may cause backwater conditions.

It is critical to key the weir into both banks and to place large rocks on the downstream face near the banks. The key provides protection from scour associated with overbank flow spilling back into the channel. Installing a key helps to prevent erosion at this critical location by reducing the potential for flanking of the weir at high flows. A minimum length for the bank key is four times the D_{100}.[3] It is also important to minimize bank disturbance and vegetation removal during construction. Buried, large woody debris can be incorporated into the bank key. Such debris should be oriented perpendicular to the overbank flows. Revegetation of the bank at both keys is necessary for added structural strength and habitat needs.

Large woody debris can be incorporated into the weir for added habitat benefit, additional roughness and flow realignment. This debris is incorporated as additional bank protection by replacing header rock(s) near the bankline with tree trunks and attached rootwads. Tree trunks should be situated parallel to the bankline as added bank protection and habitat. (Refer to Appendix I, *Anchoring and Placement of Large Woody Debris* for further guidance.)

BIOLOGICAL CONSIDERATIONS

Mitigation Requirements for the Technique

Placement of porous weirs in the channel will alter the thalweg alignment. Existing spawning areas may be impacted by new scour patterns that result from the redirected thalweg. Porous weirs, however, allow flow and sediment to pass through the structure, which may result in establishment of new spawning areas, possibly avoiding the need for mitigation as a result of the loss of spawning areas. It is important to configure the weir such that it does not significantly backwater upstream reaches, particularly during flows that result in scour and habitat development. Relocation of the thalweg could represent a lost opportunity for future development of near-bank pool habitat. Habitat value may be increased by incorporating large woody debris into the structure along the bankline, as mentioned in the previous section.

Refer to Chapter 4, *Considerations for a Solution* and the matrices in Chapter 5 for additional guidance concerning mitigation.

Mitigation Benefits Provided by the Technique

Porous weirs may provide habitat by creating turbulence cover and a diversity of deep scour holes, eddies and velocity chutes. They also catch debris, provide aeration and collect and sort gravel in the tailout for spawning habitat. The spacing between header rocks will create scour pools that are good feeding stations for larger trout, coho (if trout are absent) and smaller fish. The surface turbulence will create hiding cover for juveniles. The structure will also provide interstitial hiding areas, particularly near the bank. During high flows, turbulence may prevent the structure from being very useful for flood refuge. If the spacing between header rocks is maintained and the head differential across the structure is minimized, fish passage should not be a problem.

Porous weirs may provide habitat complexity by breaking up a long glide or riffle into different gradients. As previously mentioned, the depth of the downstream pool adjacent to the eroding bank will likely be reduced by redirection of the thalweg away from the eroding bank. These bankline pools provide some of the best types of rearing habitat, especially those with wood in them and cover from the overhanging bank. The reduction in pool habitat can be mitigated by creation of scour pools and placement of large woody debris on the downstream side of the weir. Refer to Matrix 3 in Chapter 5 for more detail on the mitigation benefits of this treatment.

RISK

Habitat

Existing spawning areas may be impacted by scour patterns that result from the redirected thalweg. By realigning the thalweg away from a downstream eroding bank, the pool adjacent to an eroding bank will be reduced. This loss in pool habitat may be compensated by new pool habitat created through scour induced by the weir.

Porous weirs will cause the bed and thalweg to shift and the banks to accrete. Depending upon the channel size, bedload movement and particle size, it may take time for the channel to adjust to this structure. In the adjustment period, spawning areas may scour or accrete and any eggs or alevins in the bed could be damaged.

Infrastructure

The risk to infrastructure situated on the streambanks is relatively low. Properly designed porous weirs focus stream energy towards the center of the channel and away from the banks.

Reliability/Uncertainty of Technique

Most of the design criteria are based primarily on gravel-bed rivers in Colorado. Design processes will be refined as more research is done for Washington river systems, including habitat needs.

CONSTRUCTION CONSIDERATIONS

Materials Required

Rock used to construct porous weirs should be sound and dense, free from cracks, seams and other defects that would enable weathering, freezing and thawing, or other natural causes to make the rock deteriorate. Rock should be angular in shape.

Timing Considerations

Porous rock weirs should be constructed during low-flow conditions to minimize instream disturbance. It is necessary to work within the stream channel to construct porous weirs. It may be necessary to dewater the channel. Dewatering can be accomplished using coffer dams to isolate work areas. Specific permitting requirements may preclude construction of porous weirs during certain times of the year (e.g., fish-spawning seasons, etc.). Instream work windows vary among fish species and streams. Contact the Washington Department of Fish and Wildlife's Area Habitat Biologist for information on work windows (see Appendix B, *Washington Department of Fish and Wildlife Contact Information*). Further discussion of construction timing and dewatering can also be found in Appendix M, *Construction Considerations*. The removal or disturbance of existing riparian vegetation during construction should be minimized.

Cost

Porous-weir structures can be a relatively low-cost approach to reducing erosive energy along a streambank. The greatest cost factor is the size of the channel. Weir structures range in cost from approximately $75 to $200 per linear foot. The cost will be determined primarily by the cost of rock available and equipment and operator rates. However, dewatering, if required, may greatly increase the cost of the treatment. Additionally, access for large equipment may require either temporary-access-road construction or the use of specialized equipment, such as a spider hoe and tracked dump trucks, to cross riparian areas for channel access and materials delivery. Refer to Appendix L, *Cost of Techniques* for further discussion of materials costs and construction costs.

MAINTENANCE

Maintenance requirement for porous weirs includes the replacement of rocks that shift or are removed by extreme flows. Any mitigation measures, such as the placement of large woody debris, may also require maintenance. This could include replacement or re-anchoring of large woody debris that may be removed or loosened by high flows.

MONITORING

Because porous-weir projects involve impacts to the channel and banks, they will require comprehensive monitoring of the integrity of the structure itself, channel and bank features, and in-channel habitat. Monitoring of porous-weir projects should be initiated prior to construction with baseline condition surveys of the physical channel, its banks and its habitat value. This should include five cross sections at intervals equal to the channel width upstream, five downstream and one at the location of the control at a minimum. This allows for the comparison of modified conditions to pre-project conditions. Additionally, monitoring should include detailed as-built surveying and photo documentation from fixed photo points of the project area and upstream and downstream reaches to allow for evaluation of performance relative to design. Details on development of a monitoring plan are discussed in Appendix J, *Monitoring*.

Monitoring of porous-weir structures should include pre-project conditions and the subsequent annual survey of key members and visual assessments of their configuration, dimensions and hydraulic function. A general qualitative description of the weir structure should also be recorded and may include such observations as the general effect on channel-flow characteristics and an approximate visual description of the structure. The general integrity of the structure should be evaluated including the identification of any significant settling of header or footer rocks as determined from survey and comparison of photos.

Impacts to the channel and to habitat must be carefully monitored. Channel changes occurring following installation can be documented by reviewing an annual survey of cross sections surveyed prior to installation and at the time of completion. Patterns of sediment deposition or scour should be noted. Similarly, changes to available habitat should be documented on a schedule dictated by fish life cycles. For a comprehensive review of habitat-monitoring protocols, refer to Johnson, et al.[4] Habitat-monitoring protocols will likely require a monitoring schedule that is more comprehensive than that required for the integrity of the structure.

REFERENCES

1 Rosgen, D. 1996. Applied River Morphology, Wildland Books, Pagosa Springs, CO.

2 U. S. Department of Agriculture, Natural Resources Conservation Service. 1998. Stream Corridor Restoration, Principles, Processes, and Practices.

3 U. S. Department of Agriculture, Natural Resources Conservation Service. 2000. Design of Rock Weirs. Technical Notes, Engineering - No. 24. U. S. Department of Agriculture, Portland, OR.

4 Johnson, D. H., N. Pittman, E. Wilder, J. A. Silver, R. W. Plotnikoff, B. C. Mason, K. K. Jones, P. Roger, T. A. O'Neil and C. Barrett. 2001. Inventory and Monitoring of Salmon Habitat in the Pacific Northwest - Directory and Synthesis of Protocols for Management/Research and Volunteers in Washington, Oregon, Idaho, Montana, and British Columbia. Washington Department of Fish and Wildlife, Olympia, WA.

Figure 6-15. Porous Weir. Blue Creek, Tributary to Walla Walla River. 1998.

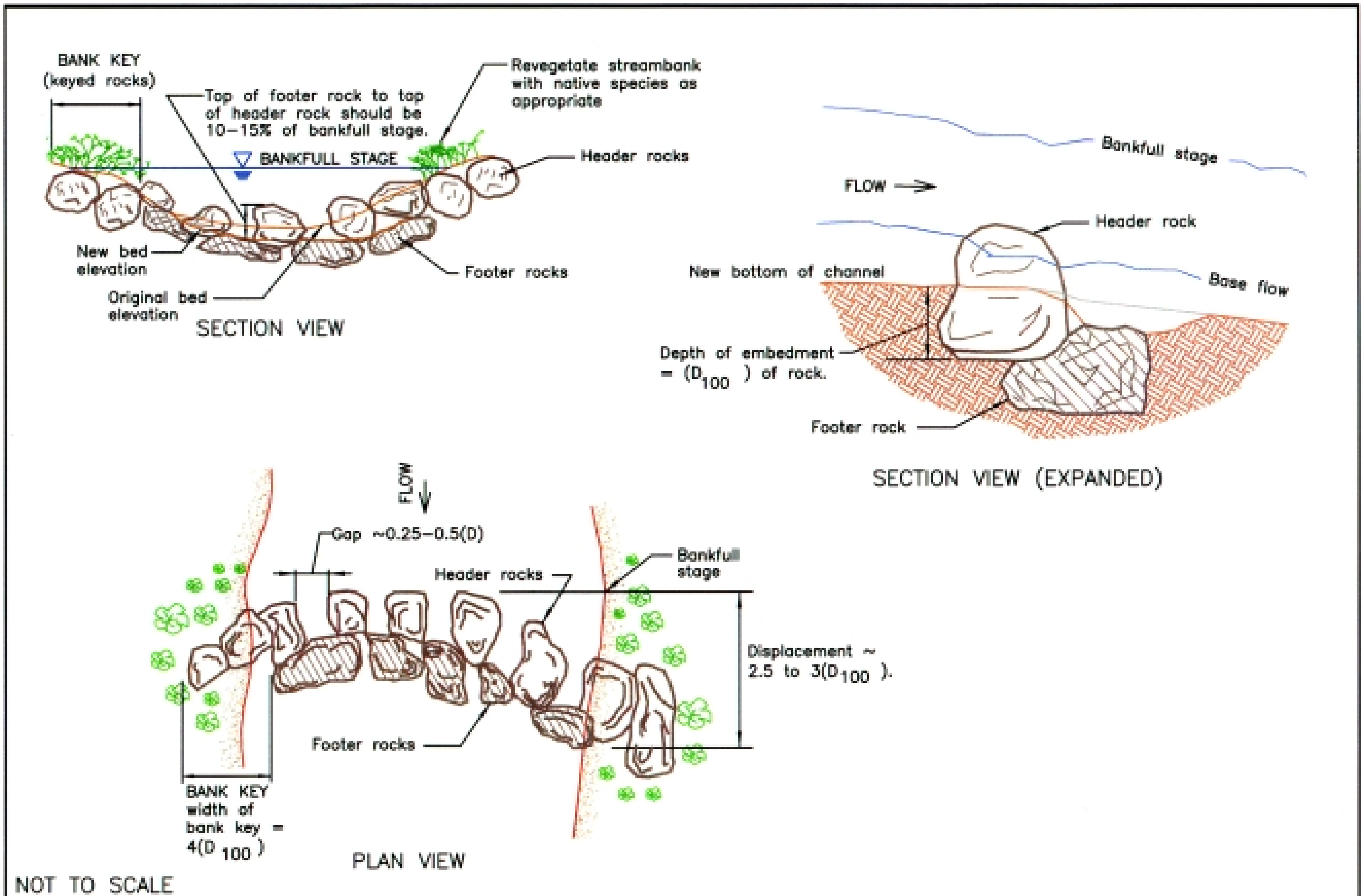


FIGURE 6–16

POROUS WEIR CONCEPTUAL DESIGN

INTEGRATED STREAMBANK PROTECTION GUIDELINES
www.wa.gov/wdfw/hab/ahg/strmbank.htm

Anchor Points

Structural Techniques

DESCRIPTION

Anchor points are either natural (e.g., tree or rock outcroppings) or artificial hard structures (e.g., rock or log trenches) at the upstream and/or downstream end of an isolated scour hole. They act to prevent or limit erosion along the bank downstream or upstream from an existing scour hole. They can be a low-cost, low-impact approach to managing isolated streambank erosion sites. *Figure 6-17*(at the end of this technique discussion) shows examples of anchor points.

APPLICATION

Typical Application

Anchor points are the preferred bank-protection technique when the mechanism of failure is scour (see Chapter 2, *Site Assessment* for more information about scour). Scour holes dissipate energy (functioning as an energy sink) with increasing volume.

The concept of anchor points is based on the principle that local scour is self-limiting; scour ceases when a scour hole has enlarged sufficiently to dissipate excess energy. Downstream and/or upstream anchor points may limit scour both longitudinally along the bank and laterally into the bank. Further expansion of the energy sink is then limited to the vertical dimension into the bed, forming a deep pool. It may initially scour further into the bank, but the extent is limited if the anchor points are successful. Protecting existing natural anchor points, such as trees, rock outcrops or debris jams, or constructing new anchor points so the scour does not expand and migrate upstream or downstream will limit the erosion along the bank. If there is not a natural anchor point, the most preferred constructed anchor point is a rock- or log-filled trench.

Anchor points may be used as a stand-alone technique, or they may be supplemented by other techniques. They are not intended to be used in braided channels or other channel systems where flow direction and hydraulics change significantly with flow level. In most braided channels, where high-flow direction differs considerably from low- and moderate-flow directions, it is difficult to predict where and at what flows anchor points will be effective. Furthermore, where anchor points may protect banks at the design flow, they may create excessive erosional forces at other flows. For further discussion of site and reach limitations, refer to Chapter 2 and Chapter 3, *Reach Assessment.* Refer to Chapter 5, *Identify and Select Solutions* and associated screening matrices for further guidance on the applicability of anchor points based on the mechanism of failure and causes of streambank erosion.

Protection of Existing Anchor Points

If there is an existing anchor point, techniques to protect it include constructing rock reinforcement around the natural anchor point or a log anchor point adjacent to it. For example, if the anchor point is a tree, constructing a rock toe around the base of the tree will protect the tree from being undermined by scour. The buttressing effects of large trees can be very effective at reducing further erosion. This natural anchor point may also need protection from surface scour that results from the overbank flow. Planting willows or other flow-resistant plants and protecting the downstream surface with rock or wood is recommended. Using launchable riprap will result in less damage to tree roots than excavating trenches around existing trees.

Rock or Log Trench

Where natural anchor points do not exist, a rock- or log-filled trench can be used. A trench is cut inland from the eroding bank and filled with rock or logs to form the anchor point at the bank line. Constructing a log-trench anchor point next to an existing anchor point can support and protect the existing anchor point. A rock- or log-filled trench is almost identical to a buried groin, except that it is built as a single structure; groins are built in a series to prevent toe and bank-surface erosion (see the discussion in this chapter addressing *Buried Groins* for additional information).

Emergency

Anchor points can be used for emergency treatment in some situations. They can be installed quickly with limited materials and equipment and with a minimum of design effort. The potential consequences of failure of installed anchor points are minimal, because the erosion they are intended to address is usually isolated and self-limiting. Additionally, anchor points can be easily mitigated.

EFFECTS

Anchoring the downstream and/or upstream end of the scour hole can limit the extent of bank erosion caused by scour. Because the anchor point limits erosion, the forces may continue to increase the volume of the energy sink by deepening an existing pool formed by scour or by further lateral erosion. The habitat benefits of existing and continued scour include preservation of the scour hole, the opportunity for either natural or constructed revegetation of the bank of the scour hole and the potential for additional accumulation of woody debris. All of these effects provide valuable pool, cover and diversity habitat.

Construction impacts are likely to be temporary and might include riparian and water-quality damage. Anchor points generally do not have long-term negative impacts on habitat, except by potentially altering the shape and location of a developing scour hole. Refer to Appendix F, *Fluvial Geomorphology* for further discussion of the potential impacts of limiting the rates and location of bank erosion.

DESIGN

A conceptual design drawing of anchor points is shown in *Figure 6-18*.

Protection of Existing Anchor Points

Protection of existing anchor points is entirely site-dependent. Usually, only enough work is needed to support the existing anchor point. If the anchor point is a tree or tree root, individual rocks can be pushed into the scour hole around the root structure or excavated into the bed to the expected scour depth. Launchable riprap can be placed around an existing tree functioning as an anchor point, to help secure the tree and eliminate risk of damage to the tree roots during installation.

Length

For constructed anchor points, the length of the trench should extend landward to prevent overbank flow from cutting a channel around the anchor point. For structural purposes, a length about three times the height of the structure is usually adequate. To prevent risk from overbank scour, tie the anchor point into higher ground or to a point where woody vegetation provides protection from surface erosion. The top elevation of the anchor point should conform to the existing ground; anchor points are not intended to change the amount or direction of overbank flow.

Rock-Filled Trench

The dimensions of the rock trench should mimic those of a buried groin (see the discussion in this chapter addressing *Buried Groins*). The lower elevation of the rock trench at the bank should be equal to the depth of scour. At that depth, the trench should extend into the bank a distance at least equal to the height of the bank. Beyond that, the depth of the trench and the size of the material are designed to satisfy the objective of surface scour behind the anchor point. In noncohesive soils, the shape of the trench will be trapezoidal or triangular and could require filter fabric to limit the rock fill from settling. In the final analysis, there should be sufficient rock so that, if the soil is eroded away, an efficient groin will result. In addition, enough fines should be present in the rock fill to support roots. Further discussion of design details of design for rock installations are available in this chapter under the section called, *Riprap*.

Log-Filled Trench

Log trenches should be filled with material appropriate for the size of the stream. In small streams, brush bundles may be adequate. In larger streams, a minimum of 12- to 18-inch-diameter logs will be required. Logs situated at the bottom of the trench should be embedded 15 to 20 feet back into the bank to resist movement. Pinning the logs together with rebar increases strength and the effective diameter of the logs (see Appendix I, *Anchoring and Placement of Large Woody Debris*). Logs can be installed in a vertical trench if ballast and support are provided. For additional design considerations on log trenches, see the discussion in this chapter addressing *Buried Groins*.

BIOLOGICAL CONSIDERATIONS

Mitigation Requirements for the Technique

Usually, anchor points require little mitigation. However, installation of rock or log trenches will result in damage to riparian vegetation associated with excavation and backfill, though replacement vegetation can be planted in the trench backfill. Since logs can be installed in a vertical trench, much less riparian area may be affected. Supporting an existing root anchor point with rock will result in the loss of the complex scour hole with the overhanging root structure. In these cases, the appropriate mitigation for this loss of habitat could be achieved by placing debris, such as large woody debris, and anchoring this material by the supporting rock, or by revegetation of the bank of the scour hole to develop additional bank complexity and cover. Excavating anchor-point trenches may affect water quality unless stream flow is diverted away from the site or the trench is excavated entirely landward of the streambank. Refer to Chapter 4, *Considerations for a Solution* and Matrix 3 in Chapter 5 for more detail on mitigation needs for this bank treatment.

Mitigation Benefits Provided by the Technique

Anchor points may increase the depth of a scour pool by limiting its migration landward or along the bank. Anchor points may accumulate debris. The increased depth and debris provide additional refuge habitat or deep-water habitat.

RISK

Habitat

Anchor points generate little risk to habitat because they do not significantly affect the channel, its banks or its processes.

Infrastructure

When applied appropriately, anchor points reduce the risk to adjacent infrastructure by limiting erosion along the channel bank and laterally into the bank.

Reliability/Uncertainty of Technique

There is a high degree of uncertainty regarding the hydraulic impact associated with this technique, because there is only a limited amount of experience with designing anchor points, and design criteria are not well tested. For these reasons, anchor points may be best applied where a low to moderate level of risk can be tolerated.

CONSTRUCTION CONSIDERATIONS

Construction considerations for the installation of anchor points include site access, dewatering, the availability of key materials and the timing of implementation.

Materials Required

Anchor points can be constructed of either rock or logs. Mature, woody, bank vegetation can be an effective anchor point. In some cases, in addition to rock, filter fabric is required to prevent installed rock from settling and to prevent piping loss of fine materials through the rock. Refer to the discussion in this chapter regarding *Riprap* for further information about materials required. The use of logs with attached rootwads provides an additional habitat value once the rootwads are exposed. Since logs are buoyant, an anchoring and ballast system is necessary. (see Appendix I).

Timing Considerations

Anchor points should be installed during low flow when dewatering is possible, and resident and anadromous fish are less likely to be impacted by construction activities. In order to install rock materials to the depth of scour, excavation within the channel bed will be necessary and, consequently, will require temporary dewatering systems. Dewatering allows for ease of installation and prevents siltation of the stream during construction. This can be accomplished with a coffer dam during low water; however, anchor points can also be constructed during high flow by installing riprap on the bank to launch around the anchor point. To limit the introduction of sediment fines to the channel, trench excavation should begin inland and proceed toward the stream bank.

Construction during critical periods in salmonid life cycles such as spawning or migration should be avoided. Instream work windows vary among fish species and streams. Contact the Washington Department of Fish and Wildlife's Area Habitat Biologist for information on work windows (see Appendix B, *Washington Department of Fish and Wildlife Contact Information*). Further discussion of construction timing and dewatering can also be found in Appendix M, *Construction Considerations*.

Cost

Anchor points are a low-cost approach to bank protection since they can provide a localized treatment as an alternative to protection along greater lengths of bank. Furthermore, since habitat impacts are less than many other options, full project costs are often relatively low. Construction costs are largely limited to materials and equipment, usually a single excavator. Consequently, costs will be largely determined by the availability of materials.

Materials and installation for rock anchor points are similar to those for riprap. Rock materials may range from $60 to $80 per cubic yard. Gravel filter materials range from $40 to $60 per cubic yard if they are imported. However, local sources may be available. Filter fabric may be used as an alternative to gravel filters and ranges in price from $0.50 to $3.00 per square yard. Materials for log anchor points will be similar to costs described in large woody debris treatments. Logs may vary in cost from $200 to $750 per log. Refer to Appendix L, *Cost of Techniques* for further discussion of materials and construction costs.

MAINTENANCE

Typical operation and maintenance requirements for anchor points include periodic inspection and installation of supplemental riprap rock or other hard material if needed. Any damage to the anchor point or mitigation features should be repaired or replaced. If erosion continues, or is exacerbated by the anchor point, the bank-protection design should be re-evaluated.

MONITORING

Monitoring should include visual inspection of the integrity of the structure, and an initial survey of the scour-hole depth and area. This will enable subsequent observations to measure development of the scour hole associated with the anchor point and to photograph the site and treatment. Anchor-point visual inspection should focus on potential weak points in the design, such as transitions between the anchor point and the unprotected bank. The adjacent native soils above and behind the treatment may reveal collapse or sinking, indicating piping loss or movement of rock materials.

Each monitoring event should include a survey of the scour hole, including depth and area, visual inspection and photo documentation. Monitoring frequency should be annual and conducted during low flows when visual inspection of the toe is possible. Additionally, monitoring should be conducted following any events that equal or exceed the one-year flow during the first three years following construction. For further discussion of monitoring methods, refer to Appendix J, *Monitoring*. For a comprehensive review of habitat-monitoring protocols, refer to Johnson, et al.[1] Habitat-monitoring protocols will likely require a monitoring schedule that is more comprehensive than that required for the integrity of the structure.

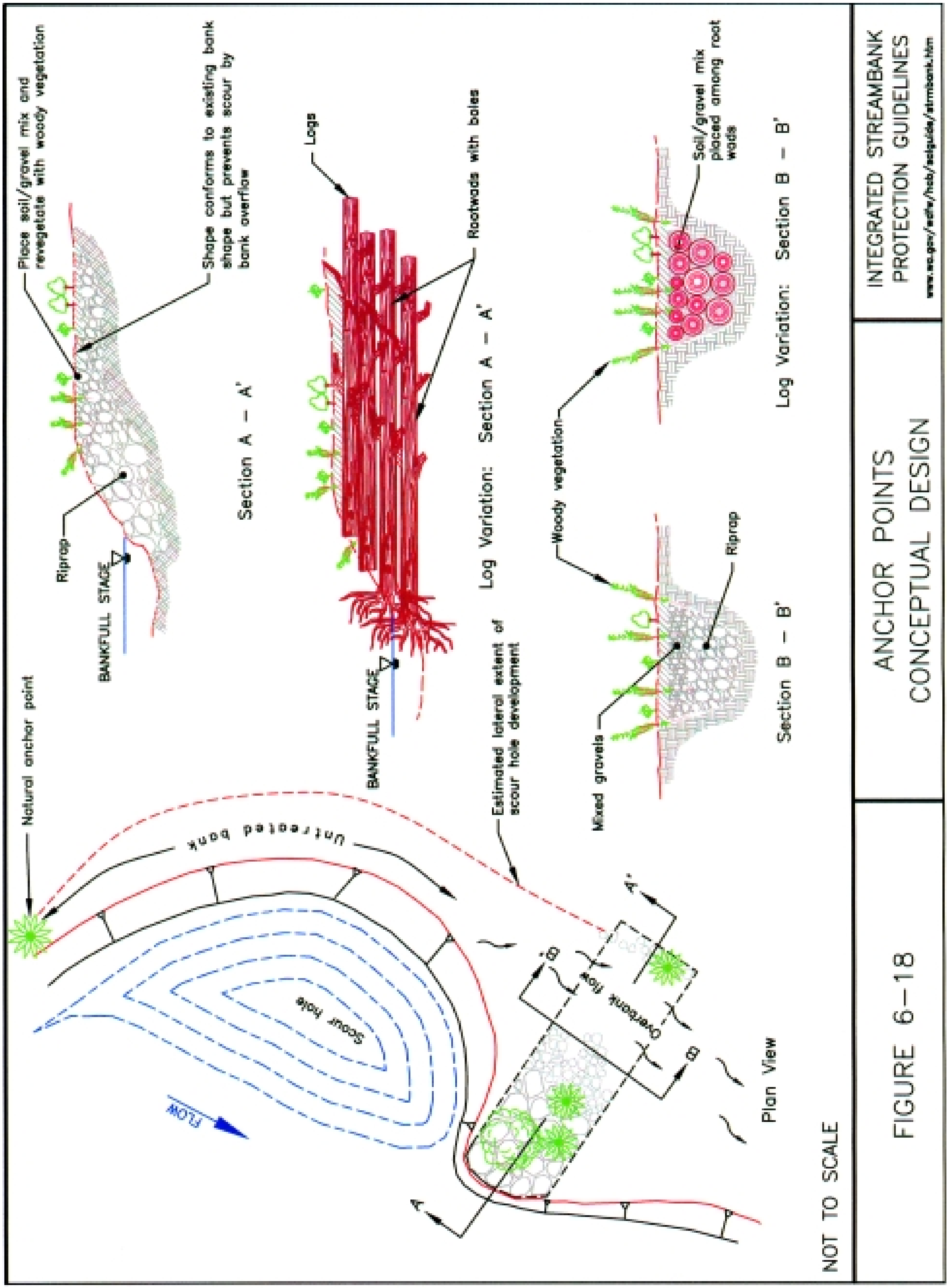
REFERENCES

1 Johnson, D. H., N. Pittman, E. Wilder, J. A. Silver, R. W. Plotnikoff, B. C. Mason, K. K. Jones, P. Roger, T. A. O'Neil and C. Barrett. 2001. Inventory and Monitoring of Salmon Habitat in the Pacific Northwest - Directory and Synthesis of Protocols for Management/Research and Volunteers in Washington, Oregon, Idaho, Montana, and British Columbia. Washington Department of Fish and Wildlife, Olympia, WA.

a. Deschutes River.

b. Newaukum River.

Figure 6-17. Examples of natural anchor points Washington State.


Natural anchor point
Untreated bank
Scour hole
FLOW
Overbank flow
Estimated lateral extent of scour hole development
Plan View
NOT TO SCALE
Place soil/gravel mix and revegetate with woody vegetation
Shape conforms to existing bank shape but prevents scour by bank overflow
Riprap
BANKFULL STAGE
Section A – A'
Logs
Rootwads with bales
BANKFULL STAGE
Log Variation: Section A – A'
Woody vegetation
Mixed gravels
Riprap
Section B – B'
Soil/gravel mix placed among root wads
Log Variation: Section B – B'
FIGURE 6–18
ANCHOR POINTS
CONCEPTUAL DESIGN
INTEGRATED STREAMBANK
PROTECTION GUIDELINES
www.wa.gov/wdfw/hab/ahg/strmbank.htm

Roughness Trees
Structural Techniques

DESCRIPTION

In many instances, the first step in controlling streambank erosion is to slow down the water velocity and reduce hydraulic shear stress. Doing so will help sediments accumulate at the site, which enables vegetation to establish itself. An effective way of slowing water velocity is to add roughness to the channel. This increases friction, which, in turn, slows down the flow. Such roughness can be introduced by installing large woody debris into the channel and along the banks. This streambank-protection technique is often referred to as "roughness trees" or "tree revetments." When positioned properly, roughness trees trap sediment, allowing the establishment of vegetation, which ultimately results in the stabilization of actively eroding banks. Nature provides many examples of how this dynamic works with the simple act of a tree falling into a stream. If its trunk and rootwad fall parallel to the bank (with the rootwad upstream), it's often easy to see where sediment has accumulated and vegetation has taken hold. *Figure 6-19* (at the end of this technique discussion) shows examples of roughness trees.

APPLICATION

Tree-roughness applications are usually applied to low-gradient alluvial channels and long, sweeping bends with vertically eroding banks where the energy is dissipated uniformly and toe erosion is the primary mechanism of bank failure (see Chapter 2, *Site Assessment* and Chapter 3, *Reach Assessment*). This technique is most appropriate where streambank soils are fine-textured. Due to the ability of roughness trees to collect and retain sediments, roughness trees can be very useful on aggrading reaches of stream, where bank erosion is associated with excess sediment supply. While typically applied to low-energy systems,[1] roughness trees may be applied to high-energy systems if the trees are large enough or anchored sufficiently to resist erosional forces of flood flows.

In general, this technique should be employed with caution, as improper tree placement may result in local scour, leading to bank failure at the upstream end of each rootwad. Roughness trees are not recommended where the mechanism of failure is mass failure, subsurface entrainment or channel avulsion. See the screening matrices in Chapter 5, *Identify and Select Solutions* for more guidance on the applicability of tree roughness based on mechanisms and causes of streambank erosion.

Variations

Variations on this treatment relate to the positioning and orientation of installed trees relative to the bank, the size of trees and the anchoring system. For example, roughness trees are typically placed with the rootwad or end of the tree angled upstream into the flow with the trunk or butt, individually anchored into the streambank. A row of trees can also be placed parallel to the water's edge, or cabled together to simulate the effect of larger trees. Ballast rocks may be incorporated into the treatment as an anchoring alternative to cables. While trees can be laid in a single tier along the base of an eroding streambank, they can also be stacked or tiered to accommodate higher banks or oriented in different positions to fit the particular conditions of a site. Roughness trees can be placed along a very steep bankline (e.g., the edge of the channel's meander corridor) to trap eroding bank materials. As the upper surface of the bank erodes, the roughness trees provide a platform for the sediment to settle, eventually resulting in the establishment of vegetation.

Emergency

This technique has limited emergency application. However, if a winter flood has eroded large portions of streambank, large wood could be installed to protect the bank, though the usefulness of this would depend upon the specifics of the site and the availability of sources of large wood nearby.

Access to the bank would also be a factor for consideration. In some cases, trees that have been undermined on-site could be repositioned to maximize their influence at reducing bank erosion. Opportunities like these occur in smaller streams because anchoring trees during high flow on larger streams may be impossible.

EFFECTS

Roughness trees reduce velocity, recruit sediment and create areas suitable for natural colonization of riparian plants. In doing so, they provide fish habitat benefits in terms of habitat complexity, cover and flood refuge. While roughness trees tend to limit the potential for gravel and wood recruitment, they can be considered degradable and ultimately deformable (with the exception of various nondegradable anchoring components such as cables and large rock). Consequently, their long-term impact to habitat is considered minimal. Roughness trees do not typically impact aquatic habitat in the short term and can provide habitat value in the form of cover and complexity along the bank.

Roughness trees have very site-specific impacts and effects, with minimal impacts to upstream or downstream reaches. The exception is when excessively large wood is used in small channels, resulting in significant impacts to channel hydraulics and depositional patterns that can be transferred upstream and/or downstream.

DESIGN

Conceptual design drawings of roughness trees are shown in *Figure 6-20*.

When designing a roughness-tree treatment, it is important to correctly size the tree relative to the stream or river. Ideally, the rootwad diameter should be equal to or greater than the bankfull discharge depth; the trunk diameter should be at least 50 percent of the bankfull discharge depth, and the total tree length should be at least 25 percent of the bankfull width. However, these dimensions are only a guideline, and they may be unrealistic for application east of the Cascades due to limited availability of such on-site resources. If trees large enough to resist the anticipated hydraulic forces of a project site are not available, smaller trees may be bound together to simulate a large tree.

In designing this technique, practitioners should be aware that it may be difficult to end up with installed roughness trees with the desired amount of "roughness" (dense quantities of fine limbs, branches and leaves). Typically, by the time trees are transported to the site, handled by an excavator and completely set in place, most of the desirable fine branches may be broken off. Every precaution should be taken to keep valuable branches intact on the trees.

The anchoring of trees requires a through understanding of the forces that are exerted on the installed trees, particularly during flood flows (see Appendix I, *Anchoring and Placement of Large Woody Debris*). Soils should also be sufficiently fine-grained to allow for anchoring. In some cases, ballast rock may be sufficient to anchor trees; but, often, it is necessary to key cabling into a trench or to a duckbill anchor. Regardless of the anchoring system, it is recommended that whole trees with rootwads be used with this technique.

For this technique, trees are usually placed at the toe of an eroding bank, with only minimal disturbance to the existing bank line. Trees should be oriented with the root mass, or larger end of the tree, pointing upstream and the trunk anchored into the streambank. Placement should proceed from upstream to downstream, so that the larger branches or root mass of the downstream tree can be placed over the upstream tree. If any trees are to be interconnected, it may be possible to connect them before final placement, but access constraints usually require that trees be interconnected after they are positioned in place. Trees should be installed such that they extend below the water line at low flows.

BIOLOGICAL CONSIDERATIONS

Mitigation Requirements for the Technique

Normally, this low-impact technique can be accomplished with minimal disturbance to habitat. However, there may be some impacts associated with construction that will require mitigation. Refer to Chapter 4, *Considerations for a Solution* for further discussion of mitigation requirements and to Matrix 3 in Chapter 5 for more detail on mitigation needs for this bank treatment.

Mitigation Benefits Provided by the Technique

Roughness trees are used to mitigate damage to riparian habitat, aquatic cover and flood refuge. Roughness trees' ability to provide resilient riparian areas may increase riparian complexity and structure. Improved riparian structure, health and complexity is beneficial to wildlife species that rely on riparian areas. Because of the habitat benefits they offer, the installation of roughness trees is considered a technique that compensates for habitat impacts. Refer to Matrix 3 in Chapter 5 for more detail on mitigation benefits provided by this bank treatment.

RISK

Risk associated with using roughness trees is usually due to poorly installed trees that shift and migrate during flood flows, causing damage to bridges and other infrastructure adjacent to the stream. During high flows, areas around large wood can be hazardous to boaters, jeopardizing human safety and property. Local river groups (rafters, fishing groups, etc.) should be notified when new wood material is placed in rivers, so that recreational users will be aware of the exact location and placement of the material. Placing warning signs upstream of the wood material to alert boaters can also help reduce this risk. Another potential risk is the blockage of culverts or bridge openings by trees that dislodge from the treatment. Regular inspection of culverts and bridges, and repositioning of displaced wood will contribute to ongoing project success.

Habitat

Woody debris improves high- and low-flow cover habitat for both adult and juvenile salmonids. While roughness trees may cause some minor, local scour (and channel-bed complexity associated with scour), they actually work to reduce scour along the bank in the long run. Roughness trees may collect and hold smaller-sized large wood and organic material. This, in turn, allows better nutrient retention and, ultimately, a greater variety and composition of macroinvertebrates for fish to eat.

Infrastructure

Large material such as anchoring rock and roughness trees must be properly sized and secured to prevent them from moving out of place and into the position of harming any infrastructure such as bridges or culverts. As roughness trees are a relatively passive and uncertain approach to bank protection, they should not be used where infrastructure is already threatened.

Reliability/Uncertainty of Technique

The reliability of this technique depends heavily on the abilities of the designer and implementer. They must be skilled at assessing whether this is the correct technique to be applied and whether the size of the trees they select can withstand flood flows. This technique is a relatively passive approach to bank protection and should only be implemented where some degree of uncertainty in outcome is acceptable.

CONSTRUCTION CONSIDERATIONS

Materials Required

A tree source is needed. Depending on the size and quantity of the wood, heavy machinery, such as an excavator, may be required to move and place large wood delivered to the site. In most cases, anchoring materials will be needed. Refer to Appendix I for further information on anchoring materials. If large trees of the proper size for the channel in question are available, anchoring materials may not be needed. Any decisions not to anchor should be based on sufficient analysis to demonstrate that the trees' length, diameter and rootwad diameter are sufficient to resist the forces of flood flows.

Timing Considerations

From a construction perspective, trees must be installed during low flow to avoid complications arising from buoyancy during installation. Any work that occurs in the channel has to be completed in designated work periods to avoid conflicts with spawning resident or anadromous fish. Critical periods in salmonid life cycles such as spawning or migration should be avoided. Instream work windows vary among fish species and streams. Contact the Washington Department of Fish and Wildlife's Area Habitat Biologist for information on work windows (see Appendix B, *Washington Department of Fish and Wildlife Contact Information*). Further discussion of construction timing and dewatering can also be found in Appendix M, *Construction Considerations.*

Cost

Roughness trees can be constructed with minimal cost relative to other structural treatments, since all necessary materials are often available on site, near site or at low cost. The cost of roughness trees (not including dewatering or other independent construction costs) may range from $40 to $80 per linear foot of streambank treated. The cost of roughness trees largely depends upon the availability of wood materials. Refer to Appendix L, *Cost of Techniques* for further discussion of materials and construction costs and for associated costs of dewatering.

MAINTENANCE

Maintenance will be necessary if monitoring reveals that anchors are failing or that roughness trees are not providing the protection anticipated.

MONITORING

Monitoring should include keeping an eye out for scour that jeopardizes the stability of the treatment. In particular, the anchoring system should be monitored and linked to maintenance if its failure would put downstream infrastructure at risk. Additionally, photo documentation should include the toe of the bank to determine whether bank erosion has been halted or reduced as a result of the installation.

Monitoring frequency should be annual and conducted during low flows, when visual inspection of the toe is possible. Additionally, monitoring should be conducted following any events that equal or exceed the one-year flow during the first three years following construction. For further discussion of monitoring methods, refer to Appendix J, *Monitoring*. Monitoring should enable the observer to determine if the structure performs according to criteria under design flows and if it provides the habitat and bank protection desired. For a comprehensive review of habitat-monitoring protocols, refer to Johnson, et al.[5] Habitat-monitoring protocols will likely require a monitoring schedule that is more comprehensive than that required for the integrity of the structure.

REFERENCES

1 Flossi, G., S. Downie et al. 1998. California Salmonid Stream habitat Restoration Manual, Third Edition. State of California Resource Agency. California Department of Fish and Game.

2 Johnson, D. H., N. Pittman, E. Wilder, J. A. Silver, R. W. Plotnikoff, B. C. Mason, K. K. Jones, P. Roger, T. A. O'Neil and C. Barrett. 2001. Inventory and Monitoring of Salmon Habitat in the Pacific Northwest - Directory and Synthesis of Protocols for Management/Research and Volunteers in Washington, Oregon, Idaho, Montana, and British Columbia. Washington Department of Fish and Wildlife, Olympia, WA.

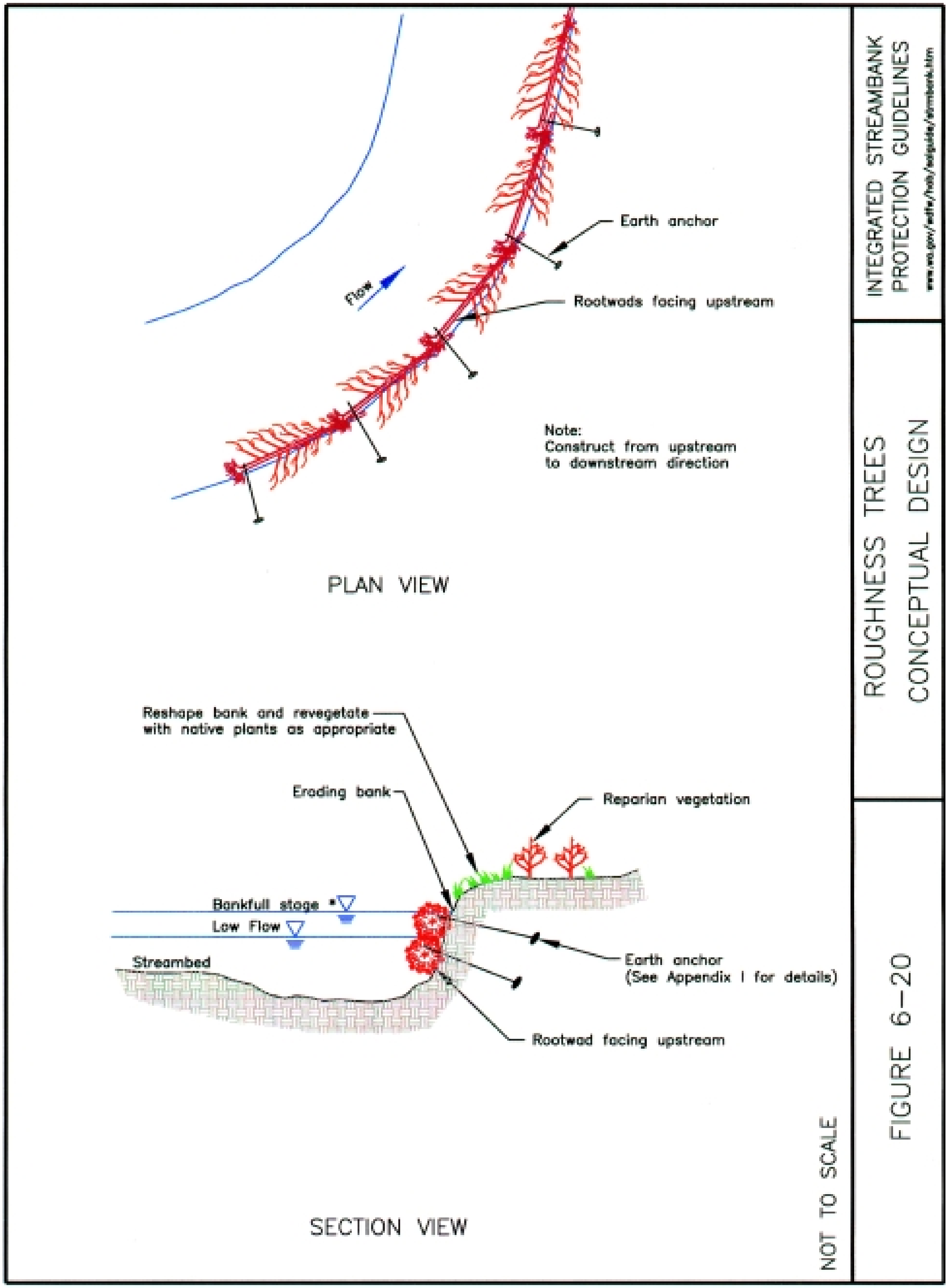
a. Unknown creek.
Source: Inter-Fluve, Inc.

b. South Fork, Nooksack River. 2002.

c. John Day River, OR.

d. South Fork, Coppei Creek, Tributary to Touchet River. 2000.

Figure 6-19. Examples of roughness trees.



Flow
Earth anchor
Rootwads facing upstream
Note:
Construct from upstream
to downstream direction
PLAN VIEW
Reshape bank and revegetate
with native plants as appropriate
Eroding bank
Reparian vegetation
Bankfull stage
Low Flow
Streambed
Earth anchor
(See Appendix I for details)
Rootwad facing upstream
SECTION VIEW
NOT TO SCALE
INTEGRATED STREAMBANK
PROTECTION GUIDELINES
ROUGHNESS TREES
CONCEPTUAL DESIGN
FIGURE 6–20

DESCRIPTION

Riprap is a type of bank armor consisting of rock, typically bedded upon a filter layer of gravel or synthetic filter fabric, with an excavated toe or launchable toe (see *Figure 6-21* at the end of this technique discussion shows examples of riprap).

Historically, riprap has been the most extensively used method for controlling bank erosion in the United States. Recently, however, concerns over the poor aquatic-habitat value of riprap and local and cumulative effects of riprap use on river morphology, have made the application of riprap controversial. For these reasons, riprap revetments are recommended only where bank failure would have intolerable consequences or where site conditions are extreme. Extreme site conditions might include high erodibility, high shear stress or mass-failure conditions.

APPLICATION

Typical Application

Riprap is typically used in bank protection and reinforcement of new stream alignments. Despite recent controversies, it is still the most widely used form of bank protection. Riprap is effective when used near infrastructure where a high risk of failure is unacceptable and where there is insufficient land between the top of the bank and adjacent infrastructure to allow alternative treatments to be used, such as toe protection and bank reshaping/revegetation. Often, riprap is used simply because it has a long history of use and the public (and many designers) are unaware of the availability and effectiveness of alternative bank treatment methods.

A properly designed and maintained riprap revetment can adjust to most scour conditions as well as general aggradation of the streambed. Assuming large enough rock is available, riprap can also be designed to withstand very high shear forces. However, the environmental consequences of riprap can be severe and should always be taken into account when selecting a bank-treatment technique.

It is important to determine whether riprap is the appropriate solution for the particular mechanism of failure and causes of bank erosion in question (see Chapter 2, *Site Assessment* and Chapter 3, *Reach Assessment* for guidance). Riprap can be useful for sites where the mechanism of failure is toe erosion, certain types of local scour, or mass failure (if used in mass-failure application, then it must be designed at a buttress). Riprap is not appropriate on sites lying within the meander-migration corridor, or on rapidly degrading reaches where the mechanism of failure has the potential for an avulsion or chute cutoff. See the screening matrices in Chapter 5, *Identify and Select Solutions* for more guidance on the applicability of riprap based on the mechanism of failure and causes of streambank erosion. Additionally, riprap's effects on local and large-scale river morphology can be troublesome (see *Effects*, later in this technique discussion).

Vegetated Riprap

A streambank surface can be vegetated by filling the voids in the riprap with soil and planting seed, by installing plant cuttings or rooted plants, or by using both of these techniques (*Figure 6-23*). Vegetation on a riprap surface offers a number of advantages. It makes for a more aesthetically pleasing bank, as well as creating favorable habitat features for fish and wildlife, including shade, leaf litter, browse and additional roughness to slow overbank flow and capture nutrient-laden sediments. Vegetated riprap is often required as mitigation for some of the habitat impacts caused by unvegetated riprap.

Large Woody Debris Placement

The impacts to aquatic habitat from riprap can be partially mitigated by the installation of large woody debris. Recent research has shown that fish of all species are generally more associated with banks stabilized with large woody debris.[1] Although large riprap provides pockets of low-velocity flow, riprap generally provides very little cover or aquatic habitat complexity. Large woody debris installed with riprap provides cover, low-velocity areas and general habitat complexity, provided it is partially or fully submerged. Large woody debris also provides roughness, which decreases velocities and dissipates energy in the form of turbulence around the large woody debris. This encourages sediment deposition, reduces overall bed scour and limits downstream effects. Refer to Appendix I, *Anchoring and Placement of Large Woody Debris* for more information.

Roughened-Rock Toes

Although riprap traditionally extends to the top of the streambank, its use can, in many cases, be limited to the area lying below the line of perennial vegetation. In this capacity, riprap stabilizes the bank toe, where scour tends to be greatest and allows for a more habitat-friendly treatment of upper streambanks. For a more extensive discussion of the use of riprap as toe protection, see the discussion in this chapter addressing the technique, *Roughened-Rock Toes*.

Windrow Riprap

Riprap is sometimes installed landward from the top of bank as a means of intercepting future bank erosion. This technique, called windrow riprap, relies on future bank erosion to expose the riprap that has been placed in a long mound, or in a trench, oriented parallel to the channel bank. As erosion accesses the windrowed riprap, the rock (or a combination of large woody debris and rock) falls into place along the face of the eroding bank. Eventually, if the riprap is large enough in size and of sufficient volume, the eroding bank will be completely armored. This technique is applied to establish a line of defense when erosion is threatening but has not yet reached important infrastructure. This approach can be used to halt erosion of upland acreage at the edge of a defined meander corridor. This concept is also presented in the context of buried groins (see the discussion in this chapter addressing the technique, *Buried Groins*).

Emergency

Riprap can be installed under emergency conditions by dumping or placing the rock from the top of the bank. As previously discussed, another way to install riprap involves placing rock material at the top of the bank, so that, as the channel erodes, the rock is launched.[2] This type of emergency installation can be carried out during flood events or immediately after floodwaters have receded. Riprap installed under emergency conditions will likely require further construction after the flood recedes to ensure it is has an adequate key and to incorporate habitat features as mitigation. Riprap may also need to be replaced by a more appropriate treatment measure that addresses the mechanism and causes of bank erosion.

EFFECTS

Riprap is very effective at arresting bank erosion and can provide relatively permanent protection against further erosion at the location where it is installed. This approach also results in a permanent lost opportunity for sediment and large-woody-debris recruitment. Downstream meander migration is arrested as well, increasing bank erosion upstream and/or downstream from the riprap protection. Because riprap is relatively permanent, it represents a long-term restraint on stream movement and must be mitigated for loss of habitat and lost opportunity.

Riprap also results in increased velocity and reduced complexity and diversity along the channel margin, thereby diminishing habitat value. These effects can be mitigated to some degree by incorporating large woody debris into the treatment and maintaining a riparian buffer. The application of riprap may deepen the channel at the bank toe and may steepen the bank slope to the point bar. This increased scour depth must be anticipated so that the toe is installed below this depth to prevent undermining.

Salmonids have been found along riprap-treated banks, but the habitat is not preferred in most cases.[1] Fish tend to like the complexity of wood structures more than rock, so logs toes and rootwads are preferred over riprap toes. Study results indicate riprap revetments with large woody debris attract more fish than plain rock. Riprap revetments along the Skagit River have had a dramatic, adverse impact on juvenile chinook, coho and chum habitat.[3] Population levels of summer coho parr and subyearling chinook averaged 3.7 and 5.4 times higher in wood cover than in riprap.

Riprap tends to transfer energy downstream. An increase in bank erosion and/or a loss of habitat in an adjacent reach can be anticipated and must be mitigated. Too often, the need for hardened banks is self-perpetuating, both in time and in the downstream direction. This increase in upstream bank erosion must be anticipated, and future impacts to habitat must be mitigated. Techniques that use hydraulic or biotechnical means to slow bank erosion must be investigated before the decision to use riprap is made. Roughening the bank with large woody debris and vegetation increases energy dissipation and is considered partial mitigation.

Given the roles of channel migration, sediment dynamics and large woody debris in a natural river system, riprap (particularly the cumulative effects of multiple riprap projects) can have significant detrimental effects on habitat and the natural fluvial processes of a river.

For a more extensive discussion of the effects of riprap on river morphology and aquatic habitat, see Appendix K, *Literature Review of Revetments*.

DESIGN

Conceptual design drawings of riprap are shown in *Figure 6-22* and *Figure 6-23*.

Riprap vs. Alternative Solutions

The first step in design is to conduct a feasibility study to determine whether riprap is the most appropriate solution based on the site and reach assessment and to ascertain whether the associated upstream and downstream effects are tolerable (see Chapter 2 and Chapter 3 for guidance). Some of the factors to be considered are stream energy (slope multiplied by discharge at the design flow), shear stress (slope multiplied by depth multiplied by a factor for radius of curvature), radius of curvature, erodibility of bed and bank material, steepness and height of banks, habitat potential and needs, acceptability of failure, and mitigation potential.

Riprap Layout

Riprap layout starts with determining the new toe-of-bank line, the upstream and downstream limits of the riprap, and the bank-face slope. These parameters determine the top-of-bank line. Occasionally, this procedure is done in reverse, particularly when property lines or structures at the top of bank limit the location of the top-of-bank line.

The revetment should include the entire area of bank erosion unless other techniques are used in combination with riprap. The location of channel features both in and outside the reach will play a role in determining where the new bank toe will be placed. Natural hard points, such as large, stable trees or rock outcroppings, are good places to begin or end the toe. Irregular toe lines increase roughness and habitat value. Smooth banks tend to increase velocity and transfer energy downstream.

To maintain bank stability, bank slopes that are 2:1 or flatter are recommended by most riprap design references, although 1.5:1 is allowable in some cases. Terracing often has hydraulic as well as habitat benefits and is a recommended practice.

Rock Size

The size of rock should be determined by accepted riprap design methods (see *Table 6-1*). Larger rock is assumed to have greater habitat value and energy dissipation. The largest rock should be used when large woody debris is incorporated in the design. As rock size increases more attention should be paid to proper bedding and granular filter design.

Filter Layer

A granular or fabric filter is necessary where soils are fine and erodible. Filters allow water behind the toe to drain without allowing soil to be transported out by the seepage or turbulence from river flow. Granular filters are composed of one or more layers of well-graded gravel. Bank-soil analysis and rock size are critical pieces of information necessary for designing a filter layer. Although a filter fabric is generally cheaper to furnish and install than a granular filter, the granular filter may be more stable. Filter fabrics can restrict rooting and produce a slip plane along which rock slopes can fail. These possibilities should be considered when deciding whether or not to use filter fabric in lieu of granular filter. Granular filters are not recommended where velocities exceed 10 feet per second.[4] See Appendix H, *Planting Considerations and Erosion-Control Fabrics* for information about fabric filters.

Depth of Scour

Scour can undermine riprap at the toe of the bank, so preventive steps must be taken to protect the bank where riprap is installed. This protection can be achieved in either of two ways:

1. a supply of riprap material sufficient to armor all expected scour is deposited on the bank. As scour erodes the bank, the ground under the riprap is undermined, and the riprap tumbles down (is launched) to the toe of the bank; or
2. a riprap layer is installed at the bank toe in advance of scour action to the depth of the scour that is expected.

The first form, known as a launched (or launchable) toe is becoming increasingly popular because it requires less excavation than the second option. However, it does require a larger volume of rock than the second option, since some rock is lost during the launching action; and final positioning of the rock cannot be determined with precision. Launched toes are used mostly in channels with fine-grained beds. Launched toes used inappropriately (for instance, along banks whose toes are eroded by some force other than scour) can result in excess rock in the channel. This extra "launchable" rock then narrows the channel and reduces habitat value.

If the second option is used, it will be necessary to calculate the anticipated depth of scour. Several methods for calculating depth of scour are presented in Appendix E, *Hydraulics*. In addition, most of the references listed in *Table 6-1* contain methods for calculating scour depth.

Top Elevation of Rock

Riprap is often applied from the toe to the top of the bank. However, riprap is seldom necessary above a certain elevation on the bank because shear force on banks decrease with height above the streambed. Consequently, the upper banks are subjected to significantly less shear than the lower-bank areas. This important characteristic of shear often allows for vegetated upper banks, thereby increasing the potential for eventually providing cover and shade. A method for estimating the shear distribution on banks is presented in Appendix E.

For further discussion about the top elevation of rock along a bank, refer to the discussion in this chapter addressing *Roughened-Rock Toes*.

Transitions

An anchor point must be located at the upstream and downstream ends of a riprap project to prevent flow from getting around and behind the revetment and eroding the bank. The design references listed in *Table 6-1* include design methods for such transitions.

It is not uncommon for a scour hole to form at the downstream end of a revetment. This hole can become an important habitat feature. Allowing this hole to form and then protecting it is a reasonable and effortless way of dealing with it. Another option is to actually create the hole at the time of construction and place a hard point downstream to limit its extent. This offers some degree of control over the exact positioning and extent of the hole. A third option is to prevent the hole from forming by installing a small groin at the bottom end of the project to kick the flow away from the bank. Roughening the toe with wood, large rock or an irregular bankline will also help prevent formation of a scour hole.

Design References

There are numerous sources of information available for riprap design. *Table 6-1* lists some of the more commonly used sources.

Vegetated Riprap

Riprap is typically vegetated by applying soil in the joints of the rock and planting seed, cuttings or rooted, woody species.

Care must be taken in arranging the soil to make sure it fills the voids between rocks but does not hold the rocks apart from one another. Rocks held apart by soil will settle when the soil is washed out by floodwaters or surface runoff, which may result in destabilization of the riprap layer. Because a small amount of this settling is inevitable, the riprap/soil layer should be slightly thicker than it would have been had no soil been used. The soil should not be installed by pouring it over the surface of the rocks; doing so will only cause the soil in this location to be readily washed away by stream flow or surface runoff. Instead, the surface of the soil should lie about one half of the mean rock diameter below the top of the rock.

Author	Title	Date
U.S. Army Corps of Engineers	*Hydraulic Design of Flood Control Channels* Engineer Manual 1110-2-1601	1994
Vanoni, V. A. (American Society of Civil Engineers)	*Sedimentation Engineering* American Society of Civil Engineers (ASCE) Manuals and Reports on Engineering Practice – No. 54	1977
U.S. Geological Survey	*Rock Riprap Protection for Protection of Stream Channels Near Highway Structures* Water-Resources Investigations Report 86-4128	1986
California Dept. of Public Works, Div. of Highways	*Bank and Shore Protection in California Highway Practice*	1970
U.S. Dept. of Transportation, Federal Highway Administration	*Design of Riprap Revetment* Hydraulic Engineering Circular, No. 11	1989

Table 6-1. Design references.

Once the soil is in place, live cuttings can be planted in the soil-filled joints between the rocks (see the discussion in this chapter addressing the technique, *Woody Plantings*). On existing riprap banks, stakes can be driven through the rock layer and soil can be placed in the voids created. If the rock is large, a pilot hole should first be created using a steel rod. Often an apparatus called a "stinger" (a large, steel rod connected to the arm of an excavator or backhoe) is required to penetrate the rock layer. Details regarding the stinger are included in the technique discussed in this chapter called *Woody Plantings*. In new riprap installations, live cuttings are inserted in conjunction with rock placement.

Planting in joints creates a more aesthetically pleasing bank and more terrestrial habitat. Vegetation planted this way can offer shade, cover and nutrient input to the stream. Woody plants will provide additional roughness and encourage deposition of fine sediment on the bank surface. The fine sediment, in turn, will foster the establishment of additional vegetation.

The discussion in this chapter addressing the technique, *Woody Plantings* and Appendix H contain additional information on incorporating woody plant species into bank treatments. The Natural Resources Conservation Service offers the following instructions regarding live-cutting size and installation procedures:[4]

- cuttings must have side branches removed and bark intact;
- cuttings must be long enough to extend well into the soil below the riprap rock and filter layer;
- cuttings should be tapped through the openings between rocks (a pilot hole created by a steel rod is usually required to avoid undue damage to the stakes);
- the cuttings should be oriented perpendicular to the bank face, with the growing tips protruding slightly from the bank surface; and
- cuttings should be placed in a random configuration.

Additionally, cuttings should be installed at the appropriate time of year. The discussion in this chapter addressing the technique, *Woody Plantings*, offers additional information on planting timing.

Placement of Large Woody Debris

Large-woody-debris installation can mitigate some of the habitat losses along a bank that has been reinforced with riprap. Information on the correct placement and anchoring of large woody debris is covered in Appendix I.

The presence of large woody debris will induce local scour forces that are not present in the standard riprap design methods. Riprap design should predict the effects that placement of woody debris will have on scour (see Appendix E) so that it the treatment can withstand this scour depth.

BIOLOGICAL CONSIDERATIONS

Traditional riprap is considered to offer little aquatic or terrestrial habitat. Peters et al.,[1] found that riprap sites consistently had lower fish densities than control sites and recommended using large-woody-debris cover whenever possible to increase the habitat value of riprap. It is strongly recommended that the mitigation strategies discussed below, or other, similar strategies, be employed to provide habitat value to riprap revetment. See Appendix G, *Biological Considerations* for a more detailed discussion of the environmental effects of riprap.

Mitigation Methods for the Technique

Mitigation needs for riprap revetments include riparian function, cover, spawning habitat, flood refuge, complexity and diversity, lost opportunity, and construction. Mitigation methods that address these needs include:

- use vegetated riprap to mitigate for riparian function impacts;
- create or enhance vegetated riparian buffer to mitigate for riparian function impacts;
- set back riprap from the channel to partially mitigate for lost opportunity impacts or include a bench in the revetment at bankfull depth;
- set large rock that creates large interstitial spaces for habitat to mitigate for flood-refuge impacts;
- place large woody debris to create roughness, pools and cover to mitigate riprap impacts to cover, complexity and diversity;
- place large boulders in the channel to create roughness and pool habitat that will mitigate riprap impacts to cover, complexity and diversity;
- increase overall complexity of the bank and channel through changes in planform, terracing, and leaving or enhancing natural features; and/or
- where possible, use riprap only to construct the bank toe, and construct the upper bank using a more "habitat-friendly" technique.

It is left to the designer to creatively apply these methods, as well as to develop alternative methods for creating aquatic and terrestrial habitat. See Chapter 4, *Considerations for a Solution* and Matrix 3 in Chaper 5, for additional information on mitigation needs and techniques.

Mitigation Benefits Provided by the Technique

Riprap provides no mitigation benefit.

RISK

Stream Function and Morphology

As discussed above, riprap can have significant, detrimental effects on the natural fluvial processes of a river by altering and interfering with natural channel migration, sediment dynamics and large-woody-debris input. Imbalances caused by riprap may lead to increased erosion elsewhere, expanding the need for bank treatment along a reach. Cumulatively, multiple riprap projects tend to lead to channel shortening, incision and degradation of aquatic and riparian habitat.

Habitat

Riprap revetments that are not mitigated by woody-debris placement or a similar alternative offer very little aquatic-habitat complexity. Although salmonids are found to use the areas adjacent to riprap revetments, it is not considered to be preferred habitat. The addition of large woody debris increases fish usage. The riparian habitat offered by the upper banks of a riprap revetment is likewise low in diversity and relatively poor in quality. Again, mitigation measures such as aggressive revegetation increase the habitat value markedly.

Infrastructure

Riprap is a proven, effective, low-risk method of protecting infrastructure. It is often the chosen bank-treatment alternative when bank failure cannot be tolerated. Unfortunately, riprap is also habitually used to protect low-risk or relatively low-energy areas where the environmental cost of the riprap may not outweigh the benefits or where other bank-treatment methods could have addressed the mechanism and causes of failure more effectively.

Reliability/Uncertainty of Technique

Compared to most other bank-treatment alternatives, uncertainty in this technique is relatively low. This is due to the simplicity of the technique, the durability of rock used in revetments, the availability of reliable design/installation guidelines and a proven, long-term track record.

Public Safety

Rock riprap revetments pose a minimal hazard to recreational users, although they may create high-velocity reaches that pose risks to inexperienced boaters. Some measures taken to enhance fish habitat, such as large-woody-debris placement, can make riprap revetments more hazardous to recreational boaters, unless the large woody debris is completely submerged. Other mitigation measures, such as adding vegetation to the riprap along the bank surface, will tend to create a safer bank. In general, safety concerns should be balanced with habitat concerns and the level and type of recreational use customary at the site.

CONSTRUCTION CONSIDERATIONS

Materials Required

Traditional riprap requires graded, angular rock and filter material. Installation will require access roads designed for street-legal dump trucks or a road for loaders to transfer the rock from trucks to the site if truck access at the site is impossible or impractical. Refer to Appendix M, *Construction Considerations* for further discussion of site access. If riprap is vegetated or large woody debris is added, the following additional materials may be needed:

- logs with rootwads attached and anchoring materials,
- vegetation (such as live cuttings or salvaged willow clumps), and/or
- soil and seed.

Further discussion of large woody debris and anchoring is provided in Appendix I. Further discussion of plant materials and planting is provided in Appendix H.

Timing

Riprap should be installed during low flow, when dewatering is possible, and when resident and anadromous fish are less likely to be impacted by construction activities. In order to install rock materials to the depth of scour, excavation within the channel bed will be necessary. This means the channel will need to be dewatered temporarily. Dewatering makes installation much easier and prevents siltation of the stream during construction. Dewatering can be accomplished with a coffer dam during times of low water flow.

Every effort must be made to avoid construction during critical periods in the salmonid life cycle, such as spawning or migration. Instream work windows vary among fish species and streams. Contact the Washington Department of Fish and Wildlife's Area Habitat Biologist for information on work windows (see Appendix B, *Washington Department of Fish and Wildlife Contact Information)*. Further discussion of dewatering can also be found in Appendix M.

Whenever vegetation is installed in conjunction with riprap revetment, the timing of seeding and planting should maximize the survival rate of the vegetation (see the discussion in this chapter addressing the technique, *Woody Plantings*).

Cost

Riprap installation cost depends upon materials availability, construction access and dewatering requirements. The cost of a riprap bank treatment may range from $30 to $90 per foot of bank treated. Cost may exceed this range on very-high-energy river systems. Dewatering and site access are further described in Appendix M.

Materials required for riprap treatments include angular rock and filter materials. Because angular rock generally must be manufactured and imported, the cost will depend largely on availability and transport costs. Rock materials may range from $60 to $80 per cubic yard. Gravel filter materials range from $40 to $60 per cubic yard if they are imported. However, local sources may be available. Filter fabric may be used as an alternative to gravel filters and ranges in price from $0.50 to $3.00 per square yard. Refer to Appendix L, *Cost of Techniques* for further discussion of materials and construction costs.

MAINTENANCE

Typical operation and maintenance requirements for riprap include periodic inspection of existing riprap and installation of supplemental riprap if needed. Planted riprap, or riprap that incorporates large woody debris, may require repair or replanting as necessary. Mitigation measures may also have operation and maintenance requirements.

MONITORING

Monitoring of riprap treatments is limited to visual inspection of the integrity of the riprap treatment. The survival rate of vegetation and anchoring success of large woody debris placed in the treatment also needs to be monitored.

Riprap inspection should focus on potential weak points in the design, such as transitions between undisturbed and treated banks. The adjacent native soils above and behind the treatment may reveal collapse or sinking, indicating piping loss or movement of rock materials. Monitoring should also include inspecting for loss of rock materials over time.

Monitoring frequency should be conducted annually during low flows, when visual inspection of the toe is possible. Additionally, the treatment should be inspected following any events that equal or exceed the one-year flow during the first three years following construction. For further discussion of monitoring methods, refer to Appendix J, *Monitoring*.

Impacts to the channel and to habitat must be carefully monitored. Channel changes occurring following installation can be documented by reviewing an annual survey of cross sections conducted prior to and following installation. Changes to available habitat should be documented on a schedule dictated by fish life cycles. For a comprehensive review of habitat-monitoring protocols, refer to Johnson, et al.[5] Habitat monitoring protocols will likely require a monitoring schedule that is more comprehensive than that required for the integrity of the structure.

REFERENCES

1 Peters, R. J., B. R. Missildine and D. L. Low. 1998. Seasonal Fish Densities Near River Banks Stabilized with Various Stabilization Methods. U. S. Fish and Wildlife Service, North Pacific Coast Ecoregion. Western Washington Office. Aquatic Resources Division, Lacey, WA.

2 U. S. Department of Transportation, Federal Highway Administration. 1989. Design of Riprap Revetment. Hydraulic Engineering Circular No. 11.

3 Beamer, E. and R. Henderson. 1998. Juvenile Salmonid Use of Natural and Hydromodified Stream Bank Habitat in the Mainstem Skagit River, Northwest Washington. Skagit System Cooperative, La Conner, WA. 55 pp.

4 U. S. Department of Agriculture, Natural Resources Conservation Service. 1996. Chapter 16 - Streambank and Shoreline Protection. Field Engineering Handbook.

5 Johnson, D. H., N. Pittman, E. Wilder, J. A. Silver, R. W. Plotnikoff, B. C. Mason, K. K. Jones, P. Roger, T. A. O'Neil and C. Barrett. 2001. Inventory and Monitoring of Salmon Habitat in the Pacific Northwest - Directory and Synthesis of Protocols for Management/Research and Volunteers in Washington, Oregon, Idaho, Montana, and British Columbia. Washington Department of Fish and Wildlife, Olympia, WA.

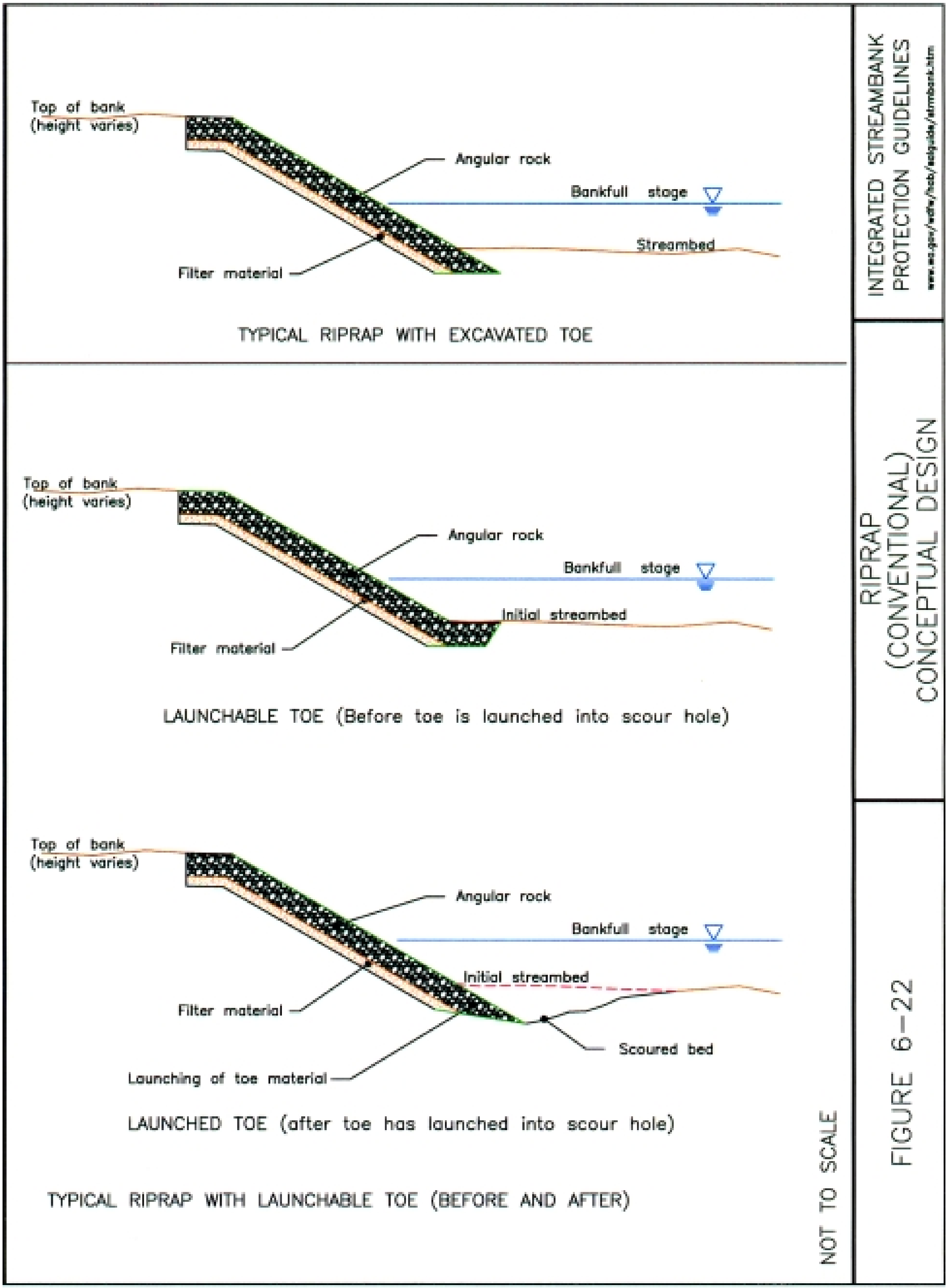
a. Riprap placed during an emergency. Tahuya River. 2002.

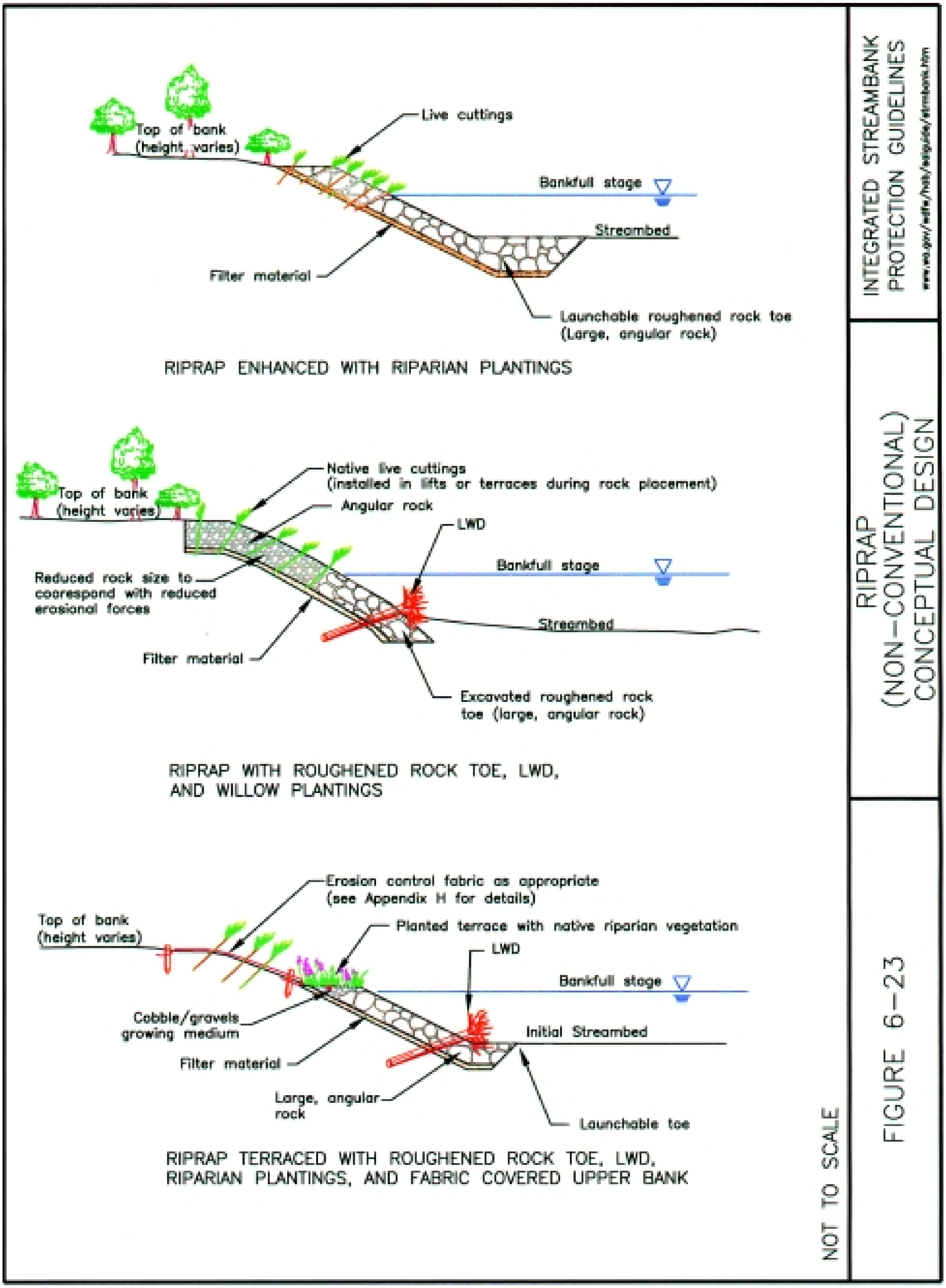
b. Nooksack River.

c. Newaukum River.

d. Vegetated Riprap. Site unknown.

Figure 6-21. Examples of riprap.


Top of bank
(height varies)
Angular rock
Bankfull stage
Streambed
Filter material
TYPICAL RIPRAP WITH EXCAVATED TOE
Top of bank
(height varies)
Angular rock
Bankfull stage
Initial streambed
Filter material
LAUNCHABLE TOE (Before toe is launched into scour hole)
Top of bank
(height varies)
Angular rock
Bankfull stage
Initial streambed
Filter material
Scoured bed
Launching of toe material
LAUNCHED TOE (after toe has launched into scour hole)
TYPICAL RIPRAP WITH LAUNCHABLE TOE (BEFORE AND AFTER)
NOT TO SCALE
INTEGRATED STREAMBANK
PROTECTION GUIDELINES
RIPRAP
(CONVENTIONAL)
CONCEPTUAL DESIGN
FIGURE 6–22



Top of bank
(height varies)
Live cuttings
Bankfull stage
Streambed
Filter material
Launchable roughened rock toe
(Large, angular rock)
RIPRAP ENHANCED WITH RIPARIAN PLANTINGS
Top of bank
(height varies)
Native live cuttings
(installed in lifts or terraces during rock placement)
Angular rock
LWD
Bankfull stage
Reduced rock size to
coorespond with reduced
erosional forces
Streambed
Filter material
Excavated roughened rock
toe (large, angular rock)
RIPRAP WITH ROUGHENED ROCK TOE, LWD,
AND WILLOW PLANTINGS
Erosion control fabric as appropriate
(see Appendix H for details)
Top of bank
(height varies)
Planted terrace with native riparian vegetation
LWD
Bankfull stage
Cobble/gravels
growing medium
Initial Streambed
Filter material
Large, angular
rock
Launchable toe
RIPRAP TERRACED WITH ROUGHENED ROCK TOE, LWD,
RIPARIAN PLANTINGS, AND FABRIC COVERED UPPER BANK
NOT TO SCALE
INTEGRATED STREAMBANK
PROTECTION GUIDELINES
RIPRAP
(NON-CONVENTIONAL)
CONCEPTUAL DESIGN
FIGURE 6–23

Log Toes
Structural Techniques

DESCRIPTION

Log toes are structural features that prevent erosion at the toe of a streambank. The toe refers to that portion of the streambank that extends from the channel bottom up to the lower limit of vegetation or to a distinct break in slope between the top of the bank and the streambed. Log toes can provide the foundation for nonrock, nonstructural, upper-bank treatments such as reinforced soil or resloped banks. Log toes are generally constructed of logs and gravel fill between logs, but may also include components made of large woody debris to provide additional habitat value. Log toes may also incorporate rock material to provide added protection.[1, 2, 3] Log toes differ from log cribwalls in two primary ways:

1. log toes are not structural retaining walls, and
2. the top elevation of log toes does not exceed the lower limit of vegetation on the bank.

Log toes are installed parallel to and at the toe of a streambank, often extending under a reconstructed bank to provide protection against erosion where erosional forces are the greatest - at the toe of the streambank. Log toes can be implemented either as a stand-alone streambank-protection technique, or as the toe element for other streambank-protection techniques. *Figure 6-24* (at the end of this technique discussion) shows various applications of log toes throughout Washington State.

Log and rootwad toes represent a more natural approach to toe protection. They may provide greater habitat value than rock for all life phases of fish and other aquatic organisms.[4] In addition, woody toe protection will deteriorate as native vegetation matures and begins to provide support and structure to the banks - an important goal of integrated streambank protection.

APPLICATION

Log toes play an important role in bioengineered approaches to streambank protection and in reshaped banks. Even so, they should be considered experimental at this point because so few have yet been designed and constructed in a systematic way. In most situations, an armored toe will provide adequate protection against erosional forces by controlling erosion where it is most prominent, at the toe[5] and by providing a relatively permanent foundation for upper-bank treatments. This approach can be applied anywhere that rock toes would otherwise be used but only where there is less risk to infrastructure and where habitat mitigation is required. For additional information, see the discussion in this chapter regarding the technique called *Roughened-Rock Toes*.

It is important to determine whether a log toe is the appropriate solution for the particular mechanism of failure and causes of bank erosion in question (see Chapter 2, *Site Assessment* and Chapter 3, *Reach Assessment* for guidance). Log toe protection is suitable for sites where the mechanism of failure is toe erosion. It is also appropriate as armoring against all types of scour if applied landward of the scour hole. Log toes are not recommended in high-energy reaches where the turbulence and shear stress would be too great, where there exists the potential for an avulsion or chute cutoff or at sites that are undergoing rapid aggradation or degradation. In aggrading reaches, the bed elevation is increasing and may overwhelm the toe. In degrading reaches the toe may be undercut and fail. In both cases, the banks experience high levels of turbulence and erosion. Use of a log toe within a channel-migration zone is preferred over a more structural technique, such as a rock toe or revetment. See the screening matrices in Chapter 5, *Identify and Select Solutions* for more guidance on the applicability of log toes based on the mechanism of failure and causes of streambank erosion.

Variations

Log toes can be installed to be either deformable or nondeformable. *Nondeformable toe-protection* techniques are designed to remain unchanged over time and to withstand erosional forces at all or most flows, thereby reducing the potential for erosion. This is accomplished with large, rot-resistant logs that do not protrude into the channel significantly (where drag could cause rotation). If log toes are to be used as nondeformable bank protection, it is important to select a type and size of wood that will resist rotting and wear. Quality of installation is also important in preventing such protection from deforming.

Deformable toes are designed to provide temporary protection, degrade with time and wear at a rate predetermined by design criteria once streambank vegetation is well established. In this type of application, log toes should be constructed using the smallest-diameter and shortest-length logs that can withstand the erosional forces acting along the bank. A deformable toe "buys time" for planted vegetation to develop root strength and eventually provide natural toe protection once the log toe disintegrates. In areas of low risk to infrastructure, the deformable toe allows restoration of natural channel migration to occur at a pace that is tempered by bank vegetation, just as it is in natural settings.

Log toes can be constructed to include large woody debris or rootwads to provide additional habitat value.[6] Large woody debris and/or rootwads installed among the logs and projecting out from the toe enhance habitat value and roughness along the bank.[3] Log toes alone may provide pockets of low-velocity flow and may provide valuable cover along the bank in spaces among the logs.

Emergency

Log toes cannot be installed in emergencies. Because logs are buoyant and must be either weighted down or anchored, log toes can only be constructed in dewatered conditions.

EFFECTS

Log toes can be very effective at controlling bank erosion. Log toes are not permanent treatment measures, which may be an advantage, since permanent protection eliminates a source of sediment and large woody debris, thereby affecting the natural balance of erosion and deposition within a channel. Also, permanent treatments arrest downstream meander migration, increasing bank erosion upstream and/or downstream from the protected bank. Because logs have a limited life span, this technique should be combined with upper-bank treatments that use bank vegetation to provide longer-term bank protection.

Log toes also result in increased velocity and reduced complexity and diversity along the channel margin, thereby affecting habitat value (though considerably less so than rock toe treatments). These effects can be mitigated to some degree by incorporating rootwads in the treatment or by varying the degree to which logs project into the channel. The hardened toe may deepen the channel at the toe and may form a point bar along the opposite bank. This increased scour depth must be anticipated so that the toe is installed low enough not to be undermined.

Rootwads incorporated in a log-toe design may produce deep scour holes due to exaggerated turbulence around them.[1] While this may provide valuable cover and holding habitat, scour must be accounted for in both the depth of the toe and in armoring the adjacent banks. Vertical log toe revetments may produce very deep scour. Studies have shown that vertical bridge abutments incur twice the scour than sloped abutments.[7] As a result, vertical revetments are not recommended.

Log toes allow for vegetated upper banks, thereby increasing the potential for eventually providing cover and shade, as compared to riprap. Additionally, many types of wood debris incorporated in log toes may sprout and grow to provide valuable root structure to the bank toe. Wood cuttings can be incorporated within a log toe to facilitate root development.

DESIGN

A conceptual design drawing is shown in *Figure 6-25*.

The first step in design is to identify whether a log toe is an appropriate solution based on the site and reach assessments (see Chapter 2 and Chapter 3 for guidance) and whether the associated upstream and downstream effects are tolerable. Many different toe-protection combinations of rocks, logs, rootwads and vegetation have been tried with varying success. Some of the factors to be considered are shear stress, depth of scour, habitat needs and potential mitigation requirements.

There are no established design criteria available for log toe structures with respect to shear stress. Consequently, log-toe design will require creative design analysis and best professional judgement. For example, log toes may be applied under virtually any shear conditions, yet how to determine the correct size of individual logs and how they are installed and anchored (which should be adjusted to accommodate differing shears) is not documented or well established.

Depth of Installation

Log toes should be installed to the maximum calculated depth of scour (refer to Appendix E, *Hydraulics* for further information). Because it is difficult to install log toes to depths greater than five feet below the bed, log toes are not recommended in areas where scour exceeds five feet. In contrast to rock toes, log toes cannot be installed as launchable material due to their buoyancy.

Log Sizing and Anchoring

The size of the logs must be large enough to withstand the hydraulic energy in the stream. However, because there are no established methods for determining the correct size of logs or method of anchoring, best professional judgement is required. Log sizes (diameter and length) should be large enough to withstand the drag forces of the river and should be anchored securely to the bank by burial.[8, 9, 10, 11, 12]

Buoyancy forces are generally not a concern if the log toe is incorporated as part of a reconstructed bank. Here, the weight of the earthen materials piled on top of the log toe is sufficient to counter the buoyancy forces. Similarly, rotational forces should not be a concern because the logs do not project into the flow. However, installation must be conducted in a water-free environment so that logs do not float during installation.

If an earthen bank treatment is not installed on top of the log toe, however, buoyancy will be the most crucial consideration for anchoring. Drag and buoyant forces need to be considered when large woody debris is incorporated into the log toe.

Some log toes have also been combined with large rocks. The rocks act as ballast and mechanically bind the structure together. It is very difficult to build a log toe along a large, deep river without using rock. See Appendix I, *Anchoring and Placement of Large Woody Debris* for more information about anchoring and ballasting.

Height of Installation

Determination of the upper elevation of the log toe is an important design consideration. The log toe should be installed at least to an elevation that corresponds with the lower limit of perennial vegetation on a streambank - the ordinary high-water line. As an alternative, criteria can be set based on shear forces along the bank and the ability of the upper-bank treatment to withstand these forces. In this case, the log toe treatment should extend to an upper elevation where such upper-bank treatments are able to withstand shear forces along the bank. The relative height of the hardened protection on the bank is a function of the erodibility of the bank and the shear stress present at the site. Refer to Appendix E for more information on bank resistance to shear stress.

Locating the New Toe Line

The location of property lines and structures has an influence over where to locate the installed bank line. But it is the location of channel features, both inside and outside the reach, that plays a role in determining where the new toe will be placed. Natural hard points, such as large, stable trees or rock outcroppings, are natural places to begin or end the toe. For additional information, see the discussion in this chapter regarding the technique called *Anchor Points.*

Base the new location for the top of the bank on the bank slope, in reference to the toe line and distance to at-risk property. Design considerations that should be addressed but are often overlooked include the location and condition of the project staging area, access for construction equipment, truck-turning needs and impacts and traffic patterns. Removal of existing riparian trees and shrubs or even disturbance of their roots should be avoided or kept to an absolute minimum. Both short-term and long-term impacts to wildlife can be greatly reduced by applying the highest possible standards of minimizing vegetation disturbance and removal.

Toe protection should be located to extend beyond the upstream and downstream limits of the bank erosion. Anchor points (rock- or log-filled trenches placed perpendicular to the toe and cut back into the bank) must be located at the upstream and/or downstream ends of the project.

Filter and Matrix Material

Log toes have a considerable amount of open space among the logs. These spaces should be filled with material consisting of a well-graded mixture of gravel, sand and other fine-grained material (similar in composition to local alluvial material is best). Additionally, a filter should be installed between the upper surface of the log toe and the upper-bank material (behind and on top of the installed logs). Filters allow water behind the toe to drain, yet don't allow soil to be transported out by the seepage or turbulence from river flow. Filter material can be either synthetic fabric or gravel material. In either case, they reduce the potential for piping loss of native soil materials through the treatment structure. A filter is generally not needed under the log toe, as logs are less dense than the native soils and alluvial material in which they are installed.

Large voids in log toes need to be plugged with rock and backed with a gravel filter to insure that the bank material is not carried out by turbulence or seepage. The toe will fail if the soil behind it is washed out, causing flow over the top to drop down and form a plunge pool behind the toe.

Placement of Large Woody Debris

If large woody debris is used, it should be incorporated into the log toes roughly perpendicular to flow direction and/or logs intentionally placed to project into the current as debris catchers. The use of large woody debris in log toes needs to consider buoyancy and rotational forces. Large woody debris must be sufficiently anchored within the log toe to eliminate the risk of pulling free and damaging the treatment. Often, the depth from the installed debris to the channel bed increases as a scour hole develops beneath the debris. Similarly, large woody debris should be installed such that the top of the wood is submerged or partially submerged to reduce the rate of decay. For more information on placement and anchoring of large woody debris, refer to Appendix I.

Transitions

Transitions are the points where the log toe treatment meets the upstream and/or downstream streambank. Anchor points are recommended as transition features for log toes. Should the biotechnical bank protection above the toe fail, the anchor points guide the flow out from behind the toe and back into the channel. Without these structures, the river could scour behind the toe along its length and cause bank failure. Anchor points must be located at the upstream and/or downstream ends of the project to prevent flow from eroding behind the bank treatment. For additional design information on anchor points, refer to the techniques described in this chapter called *Riprap* and *Anchor Points*.

BIOLOGICAL CONSIDERATIONS

Mitigation Requirements for the Technique

Log toes may be constructed as a deformable or nondeformable treatment. By locking a streambank in place, the nondeformable treatment results in lost opportunity for sediment supply, recruitment of woody debris and off-channel spawning and rearing habitat (for further discussion of lost opportunity, refer to Chapter 4, *Considerations for a Solution*). Short-term lost opportunity will need to be mitigated. Once a log toe has degraded, lost opportunity is no longer a concern. Log toes can be expected to last from years to decades depending upon factors such as type of wood, size of wood, consistency of submersion and flow characteristics.[13]

If designed to degrade over time, log toes can provide for immediate toe protection without permanently jeopardizing recruitment of gravel, large woody debris or off-channel habitat. Where recruitment is permanently jeopardized, mitigation will be required. Refer Chapter 4 for further discussion of mitigation requirements and to Matrix 3 in Chapter 5 for more detail on mitigation needs for this bank treatment.

Mitigation Benefits Provided by the Technique

Log toes can be designed and constructed to incorporate rootwads as partial mitigation for cover, complexity and diversity, and flood refuge. Rootwads will produce a velocity break and small-scale cover for both juvenile and adult fish. Fish tend to prefer wood for cover better than rock, so logs and rootwads are recommended over rock toes.[4] Access to woody debris, both in summer and winter, is critical for many salmonids.

Log toes are constructed of native materials (if available) and may be considered degradable. The wood material may provide complexity and diversity to the streambank and may result in vegetated bank toes if the wood generates shoots. Additionally, log toes offer an advantage over riprap treatments in that the upper bank can be designed to provide considerable riparian habitat, cover and shade. Design of upper banks should therefore incorporate vegetation elements that provide the maximum degree of habitat potential to the stream channel. Refer to Matrix 3 in Chapter 5 for more detail on mitigation benefits provided by this bank treatment.

RISK

Log toe treatments are similar to rock toe treatments in that they provide a relatively low-risk and reliable approach to streambank protection, except that less non-native material is required for log toes, and there is a greater potential for habitat mitigation than with rock toes. Log toes are relatively new, and design experience is limited. As noted earlier, they should be considered experimental. The use of rootwads and log toes that project into the stream's main flow may be a hazard to humans recreating in or along the stream. For this reason, risks associated with recreational activities (e.g., fishing, boating) should be taken into account before selecting this technique. Signage upstream from a log toe may be helpful in warning recreational users of potential hazards and should be included as a design consideration.

Habitat

Log toes harden the bank into a relatively uniform and permanent position and shape, resulting in short-term lost opportunity for sediment supply, recruitment of large woody debris and off-channel habitat. Even so, log toes are considered superior to rock toes in terms of providing habitat elements, and log toes will eventually degrade; rock will not. Therefore, log toes can be considered as deformable (albeit over long periods of time) and, as such, will not result in permanent lost opportunity.

Infrastructure

When applied correctly, log toes reduce the risk to adjacent infrastructure by limiting erosion along the channel bank and laterally into the bank.

Reliability/Uncertainty of Technique

Similar to rock toes, log toes provide a reliable approach to arresting or preventing erosion. However, the uncertainty in this approach is twofold. First, there are no established guidelines or methods for determining the correct log size needed or for installing the treatment. Second, there is additional uncertainty regarding the integrity of upper-bank components. However, development of design guidelines will eventually be possible if adequate monitoring of these projects is conducted relative to their design criteria.

CONSTRUCTION CONSIDERATIONS

Materials Required

Materials necessary for log toe treatments include logs, material to fill spaces among logs, filter material (gravel or fabric) and large woody debris for mitigation and habitat components. For further discussion of filter materials and large woody debris, refer to the treatment described in Appendix H, *Planting and Erosion-Control Fabrics* and Appendix I.

The type of wood selected may be a important if longevity of the protection is a concern.

Avoid using species such as alder or cottonwood that decay rapidly, unless deformable treatments are desired. Coniferous species such as cedar, fir and pine are better choices. However, on smaller streams, logs that may ultimately sprout should be considered as supplemental to promote woody growth on the streambank. There are manufactured alternatives to using logs. One such product is manufactured by ELWd Systems.[14] Natural logs are simulated using organic materials and come in a range of lengths and diameters. They have been used on several log toe projects in western Washington.

Logs should be scaled appropriately to the channel characteristics and hydrology. Logs need to have sufficient length under the bank to resist being pulled out. Logs in a log toe are not intended to protrude into the channel (except to catch debris) and, therefore, will not need to resist significant drag forces. It is more important to select logs that can be installed as an integrated unit than to select large-diameter logs.

Timing Considerations

Log toes are best constructed during low flow when dewatering is possible and, when resident and anadromous fish are less likely to be impacted by construction activities. In order to install logs to the depth of scour, excavation within the channel bed will be necessary and, consequently, will require temporary dewatering systems. Dewatering allows for ease of installation and prevents siltation of the stream during construction. This can be accomplished with a coffer dam during low water.

Critical periods in salmonid life cycles, such as spawning or migration, should be avoided. Instream work windows vary among fish species and streams. Contact the Washington Department of Fish and Wildlife Area Habitat Biologist for information on work windows (see Appendix B, *Washington Department of Fish and Wildlife Contact Information*). Further discussion of construction timing and dewatering can also be found in Appendix M, *Construction Considerations.*

Cost

Log toe treatments can be constructed with minimal cost relative to other toe treatments, since all necessary materials are often available on site, near site or at low cost. The cost of log toe treatments alone (not including upper-bank treatment, dewatering or other independent construction costs) may range from $20 to $60 per linear foot of toe treatment. Cost of the toe treatment itself will be most dependent upon availability of log materials. The cost of log toe treatments largely depends upon the size of the river (which impacts dewatering costs) and wood materials required. Additionally, the cost of the associated upper-bank treatment will greatly affect overall cost. Refer to Appendix L, *Cost of Techniques* for further discussion of materials and construction costs and for associated costs of dewatering and upper bank treatments.

MAINTENANCE

Maintenance needs are generally minimal if logs are installed under a constructed upper-bank treatment, as opposed to being anchored to the toe at the surface of the bank. Maintenance can be relatively challenging, as it may be difficult to place additional logs to patch up destabilized sections of the log toe treatment without dewatering the work area. Repair of damaged bank-toe sections may be best accomplished by using rock instead of logs.

In addition to maintaining the toe treatment, any mitigation components incorporated will need to be monitored and maintained. Large woody debris and other installed habitat components will also require monitoring and maintenance.

MONITORING

Monitoring log toe treatments is limited to survey and visual inspection, including regular photo documentation. Monitoring components should include survey and inspection of the integrity of the log toe treatment and associated upper-bank treatments. Monitoring components of upper-bank treatments is further discussed under the relevant upper-bank treatments (e.g., bank reshaping, soil reinforcement, herbaceous plantings, woody plantings, coir logs) described in this chapter.

Monitoring should include detailed as-built surveying and photo documentation of the project area and upstream and downstream reaches to evaluate performance relative to design. Details on development of a monitoring plan are discussed in Appendix J.

Log-toe-monitoring activities should focus on potential weak points in the design, such as transitions between undisturbed and treated banks and between the log toe and the upper bank. Monitoring should include surveying the location and elevation of the log toe at upstream and downstream limits, and at 50-foot intervals along the treatment. The adjacent native soils above and behind the treatment may reveal collapsed or sinking fill, indicative of piping loss or movement of log materials. Additionally, monitoring should include inspection for degradation and/or loss of log-toe materials over time.

Monitoring frequency should be annual and should be conducted during low flows, when visual inspection of the toe is possible. Additionally, monitoring should be conducted following any events that equal or exceed the one-year flow during the first three years following construction. For further discussion of monitoring methods, refer to Appendix J.

For a comprehensive review of habitat-monitoring protocols, refer to Johnson, et al.[15] Habitat-monitoring protocols will likely require a monitoring schedule that is more comprehensive than that required for the integrity of the structure.

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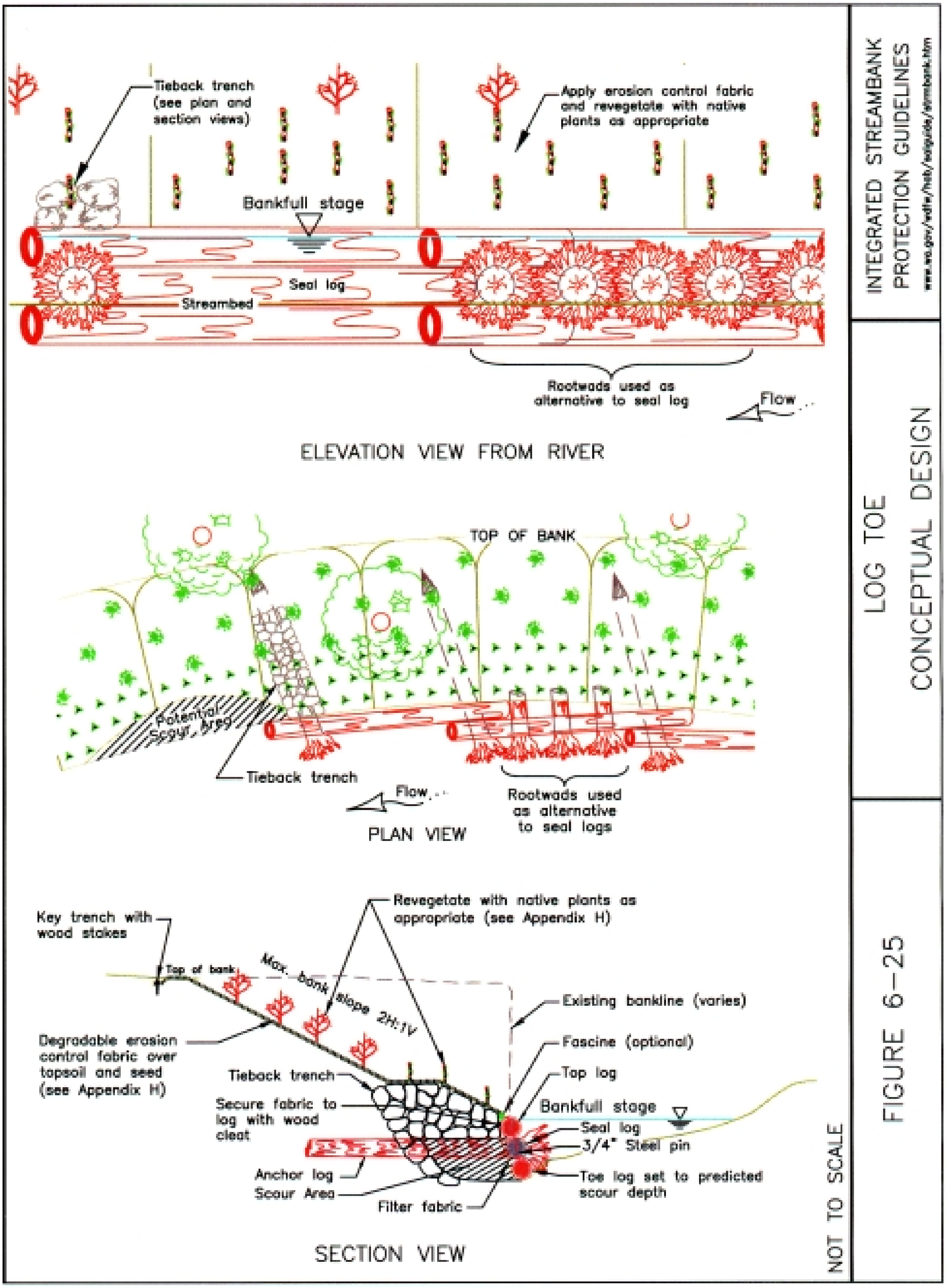
a. Log Toe with rootwads, boulders, soil reinforced lifts and plantings. One year after construction. Green River. 1994.
Source: King County Department of Natural Resources.

b. Log Toe with rootwads, boulders, soil-reinforced lifts and plantings. Four years after construction. Green River. 1998.
Source: King County Department of Natural Resources.

c. Log Toe with bank reshaping and plantings. Dungeness River. 1995.

Figure 6-24. Various applications of log toes throughout Washington State.



Tieback trench (see plan and section views)
Apply erosion control fabric and revegetate with native plants as appropriate
Bankfull stage
Seal log
Streambed
Rootwads used as alternative to seal log
Flow
ELEVATION VIEW FROM RIVER
TOP OF BANK
Potential Scour Area
Tieback trench
Flow
Rootwads used as alternative to seal logs
PLAN VIEW
Key trench with wood stakes
Top of bank
Max. bank slope 2H:1V
Revegetate with native plants as appropriate (see Appendix H)
Existing bankline (varies)
Degradable erosion control fabric over topsoil and seed (see Appendix H)
Fascine (optional)
Top log
Tieback trench
Bankfull stage
Secure fabric to log with wood cleat
Seal log
3/4" Steel pin
Anchor log
Scour Area
Filter fabric
Toe log set to predicted scour depth
SECTION VIEW
NOT TO SCALE
INTEGRATED STREAMBANK PROTECTION GUIDELINES
LOG TOE CONCEPTUAL DESIGN
FIGURE 6-25

Roughened-Rock Toes
Structural Techniques

DESCRIPTION

Roughened-rock toes are structural features that prevent erosion at the toe of a streambank (see *Figure 6-26* at the end of this technique discussion). The toe is where a streambank is most vulnerable because that is where the erosional forces are greatest. When roughened-rock toes are properly installed, they can withstand these forces and provide the foundation for upper-bank biotechnical treatments, such as reinforced soil lifts or vegetative plantings.

Smooth-rock toes alone generally provide little habitat complexity or cover. Roughened-rock toes, by definition, are designed with angular components, which provide greater roughness. Large woody debris may be incorporated into roughened-rock toes as a habitat feature and to provide additional roughness. Roughened-rock toes extend from the maximum predicted depth of scour to the lower limit of vegetation - the point of elevation on the bank where plant growth cannot be expected to hold the soil together. A roughened-rock toe can be created by launching material from the bank during scour events, which ultimately provides the toe with protection to the depth of scour.

APPLICATION

Roughened-rock toes are used in bank protection and in the reinforcement of new stream alignments. In most situations, an armored toe will provide substantial protection against erosional forces by controlling erosion where it is most prominent, at the toe and by providing a relatively permanent foundation for upper-bank treatments. This approach can be applied anywhere that riprap would otherwise be used; but there must be less risk to infrastructure, and habitat mitigation must be incorporated into the treatment. Roughened-rock toes can also be employed as a complementary toe treatment for bioengineered streambank protection and for reshaped banks.

It is important to determine whether a rock toe is the appropriate solution for the particular mechanism of failure and causes of erosion in question (see Chapter 2, *Site Assessment* and Chapter 3, *Reach Assessment* for guidance). Roughened-rock toe protection is appropriate for sites where the mechanism of failure is toe erosion. It is also suitable armoring against all types of scour if applied landward of the scour hole. This treatment is not appropriate at sites where the potential for an avulsion or chute cutoff exists or at sites that are undergoing rapid aggradation or degradation. In aggrading reaches, the bed elevation is increasing and may overwhelm the toe. In degrading reaches the toe may be undercut and fail.

It is also not advisable to use a nondeformable, roughened-rock toe within a channel-migration zone since it will interrupt the natural, riverine-channel-migration process and will likely cause future erosion problems upstream and downstream. See the screening matrices in Chapter 5, *Identify and Select Solutions* for more guidance on the applicability of rock toes based on the mechanisms of failure and the causes of streambank erosion.

Variations

Roughened-rock toes can be installed in such a way that they are either nondeformable or deformable. Nondeformable bank-protection techniques are designed to resist change over time. They are designed to withstand erosional forces at all or most flows, thereby reducing the potential for erosion. Roughened-rock toe protection is typically designed as a nondeformable bank-protection technique.

Deformable bank-protection techniques, on the other hand, allow for a natural rate of erosion to occur along reconstructed streambanks. These techniques are designed to provide temporary protection, but will degrade with time once streambank vegetation is well-established, according to predetermined design criteria. In such cases, roughened-rock toes may be designed to deform by constructing them from gravel wrapped in biodegradable erosion-control fabrics. The fabric-wrapped gravel provides a structural treatment for as long as the fabric's integrity remains. As the fabric gradually begins to degrade, the gravel can be gradually eroded. By that time, the above-water portion of the bank will be vegetated, thereby resisting erosion.

Roughened-rock toes are often constructed with large woody debris incorporated into them to provide habitat value and roughness features. Recent research has shown that fish of all species are more likely to gravitate to banks that are stabilized with large woody debris than those banks that are reinforced with rock alone.[1] The impacts to aquatic habitat from rock toes can be partially mitigated by the installation of large woody debris. Submerged or partially submerged large woody debris installed in concert with a roughened-rock toe provides cover, reduces velocity areas and creates habitat complexity. The additional roughness provided by the large woody debris dissipates energy in the form of turbulence, which results in sediment deposition and reduction in bed scour and downstream effects. Refer to Appendix I, *Anchoring and Placement of Large Woody Debris* for more information on placement and anchoring of large woody debris.

Toe reinforcement can also be constructed using logs instead of rock. Log toes are described in this chapter under the technique entitled, *Log Toes*.

Emergency

When a bank is actively failing during an emergency, rock is typically installed to armor the toe of the bank and arrest further erosion. Rock toes can be installed by dumping or placing the rock from the top of the bank and allowing it to fall into the channel along the bank toe. Another installation technique is achieved by placing rock at the top of the bank, so that, as the bank erodes, the rock is launched.[2] This type of emergency installation can be carried out during flood events or immediately after flood waters have receded. Rock installed under emergency conditions will require further construction after the recession of flood waters to ensure it has an adequate key (situated below the design scour depth) and to incorporate habitat measures as mitigation. In such cases, there is the potential for salvage and re-use of some rock materials following the emergency. The rock may also need to be replaced by a more appropriate treatment measure that addresses the mechanism of failure and causes of bank erosion, as discussed in Chapter 2 and Chapter 3.

EFFECTS

Rock toes are very effective at arresting bank erosion and can provide relatively permanent protection against further erosion. This approach also eliminates the streambank as a source of sediment and recruitment of large woody debris, which affects the natural balance of erosion and deposition within a channel. Also, downstream meander migration is arrested, increasing bank erosion upstream and/or downstream from the rock toe protection. Because rock toes are permanent, they represent a long-term restraint on stream movement and must be mitigated for loss of habitat and lost opportunity.

Rock toes also result in increased velocity and reduced habitat complexity and diversity along the channel margin. These effects can be mitigated to some degree by incorporating large woody debris into the treatment and by maintaining a riparian buffer. A hardened toe may deepen the channel at the toe and may steepen the slope to the point bar. This increased scour depth must be anticipated so that the toe is installed below this depth to prevent bank undermining. In contrast to riprap approaches, which extend up the bank, rock toes allow vegetation to continue growing along the upper banks, thereby increasing the potential for cover and shade.

Fish tend to prefer the complexity of wood structures more than rock, so log toes are the preferred bank-protection option over rock toes. Salmonids are found along riprap banks, but the habitat is not preferred in most cases where they have a choice.[1] Rock toes and revetments with large woody debris have been shown to have more fish abundance than plain rock.

Rock toes tend to transfer energy downstream. An increase in bank erosion and/or a loss of habitat in an adjacent reach should be anticipated and must be mitigated. Too often, the installation of hardened banks creates a snowball effect, wherein the placement of one hardened-bank treatment creates the need for more hardened bank segments to control the upstream and downstream erosion problems caused by the first hardened-bank treatment. Alternative techniques that use hydraulic or biotechnical means to slow bank erosion must be considered before the decision to armor the bank is made. If bank hardening simply must be done, roughening the toe with wood will dissipate flow energy along the bank and will count as partial mitigation.

DESIGN

The first step in design is to identify whether a rock toe is an appropriate solution based on the site and reach assessment (see Chapters 2 and 3 for guidance) and whether the associated upstream and downstream effects are tolerable (see Chapter 5 for guidance). Many different combinations of rocks, logs, rootwads and vegetation have been tried with varying success. Some of the factors to be considered are shear stress, radius of curvature, erodibility of bed and bank material, habitat needs, and mitigation potential. Design elements for rock toes include depth of installation, size gradation of installed rock, thickness of installation and a filter between native soil and rock. Conceptual design drawings are shown in *Figure 6-27.*

Depth of Scour

There are two approaches for installing rock to accommodate scour. Rock toes can be installed to the depth of anticipated scour or by installing a launchable volume of rock on the channel bed at the toe of the bank (refer to Appendix E, *Hydraulics* for further information on calculating scour). In the latter case, an additional volume of rock is necessary to fill scour holes as they develop. The launchable volume should be placed at the toe of the bank as an extra thickness of rock above the channel bed. Valuable habitat has been needlessly eliminated when launched toes have been used on beds that do not scour, so it's important to be certain that launched toes are the appropriate solution for the circumstances at hand.

Rock Size

The correct size of rock should be determined by accepted riprap design methods (see design references in the discussion about *Riprap* in this chapter). Since larger rock is assumed to have greater habitat value and energy dissipation, rock toes should include rock along the toe line that is larger than that which is required to resist erosion alone. Similarly, large rock should be used when large woody debris is incorporated into the design to help secure the debris. As increasingly larger sizes of rock are incorporated, extra attention should be paid to proper bedding and granular-filter design.

Top Elevation of Rock Toe

Determination of the upper elevation of the rock toe is an important design consideration. The rock toe should be installed at least to an elevation that corresponds with the lower limit of vegetation on a streambank - the ordinary high-water mark. Alternatively, criteria may be set based on shear forces along the bank and on consideration of the ability of the upper-bank treatment to withstand these forces. Properly designed and installed rock toes can generally withstand shears of between two and four pounds per square foot for rock having a D_{50} (mean diameter) of between six inches and 12 inches, respectively. In this case, the rock toe treatment should extend to an upper elevation at which associated upper-bank treatments are able to withstand shear forces along the bank. On high-shear-stress banks, the top of the rock may have to be located higher on the bank than in streams with lower flood depth and lower slope. A method for estimating the shear distribution on banks and a list of shear resistance to various bank treatments is presented in Appendix E.

Locate the New Toe Line

The locations of property lines and structures have an influence on the location of the bank line, but the location of channel features both in and outside the reach will play a role in determining where the new toe will be placed. Natural hard points, such as large, stable trees or rock outcroppings, are natural places to begin or end the toe. Irregular toe lines increase roughness and habitat value. Smooth banks tend to increase velocity and transfer energy downstream.

Begin and end toe protection outside the area of bank erosion. An anchor point (a rock- or log-filled trench placed perpendicular to the toe and cut back into the bank) must be located at the upstream and/or downstream ends of the project to prevent flow from eroding behind the toe. The scour hole that usually appears at the downstream end of a project may be an important habitat feature. Allowing this hole to form and then protecting it is one option. Another option is to create the hole at the time of construction and place a hard point downstream to limit its extent. These scour holes are less likely to form if the toe is roughened with wood, large rock or an irregular bankline.

Bank Slope

Upper-bank slopes that are 2:1 or flatter are recommended by most riprap design references, although 1.5:1 is allowable in some cases. Steeper upper-bank slopes require the use of soil pillows or other soil-stabilization techniques. Terracing has hydraulic as well as habitat benefits and is a recommended practice. It also improves constructability. Determine the new location of the top of the bank on the basis of bank slope in reference to property lines and structures.

Filter Material

Filters are often necessary underneath and behind installed rock because they reduce the potential for piping loss of native soil materials through the rock, and they prevent the installed rock from sinking into soft native materials, while allowing water to drain through them. Additionally, when rock toes are used as the foundation for upper-bank treatments, gravel filters are necessary on top of the installed rock toe to prevent loss of upper-bank materials through the rock toe. For additional information about filters and preventing loss of bank materials, refer to the discussion in this chapter on *Subsurface Drainage Systems*.

Filter material can be either synthetic fabric or gravel material. Granular filters are composed of one or more layers of well-graded gravel. There are design specifications that depend on bank soil analysis and rock size. It should be noted that fabrics may inhibit installation of live cuttings, restrict rooting and produce a slip plane along which rock slopes can fail.

Placement of Large Woody Debris

Large woody debris placed into rock toes should be designed to withstand buoyancy and rotational forces. The debris must be well anchored into the rock to eliminate the risk of the wood's buoyancy or leverage causing the it to pull free and impact the integrity of the toe treatment. Large woody debris installed in rock toes should be positioned such that it provides cover and has the potential to collect additional debris and bed material. For further detail on placement of large woody debris and anchoring, refer to the Appendix I.

Transitions

Transition points are the places where the roughened-rock treatment meets the upstream and/or downstream streambank. Anchor points are recommended as transitions on rock toes. These are rock-filled trenches placed perpendicular to the toe and cut back into the bank. An anchor point must be located at the upstream and/or downstream ends of the project to prevent flow from eroding behind the revetment. The design references that are listed in *Table 6-1* (see the discussion about *Riprap* in this chapter), includes design methods for such transitions.

Should the biotechnical bank protection above the toe fail, the anchor points guide the flow out from behind the toe and back into the channel. Without these trenches, the river could easily scour behind the toe along its length and cause bank failure.

BIOLOGICAL CONSIDERATIONS

Mitigation Requirements for the Technique

Rock toes are typically designed as a nondeformable toe treatment. By locking a streambank in place, rock-toe treatments result in lost-opportunity impacts for sediment supply, woody-debris recruitment and for off-channel spawning and rearing habitat. For further discussion of lost opportunity, refer to Chapter 4, *Considerations for a Solution.*

Rock toes reduce habitat potential by armoring the streambank toe and reducing variability and complexity, as well as increasing velocity. In an effort to mitigate these impacts, large woody debris can be placed within the rock toe. Additionally, it is possible to install rock toes in an irregular fashion such that the rock itself provides some degree of variability along the toe. Refer to Chapter 4 for further discussion of mitigation requirements and to Matrix 3 in Chapter 5 for more detail on mitigation needs for this bank treatment.

Mitigation Benefits Provided by the Technique

There is no mitigation benefit provided by rock toes perse; however rock toes offer an advantage over riprap treatments in that the upper bank can be designed to provide considerable riparian habitat, cover and shade. Design of upper banks should incorporate vegetation elements and riparian buffer management to provide the maximum degree of habitat potential to the adjacent stream channel.

Beneficial techniques that should be considered and possibly included in rock-toe projects are listed below (these features mitigate for themselves):

- planting vegetation in the joints between the rocks or using vegetated riprap to restore streambank vegetation;
- creating or enhancing vegetated riparian buffer;
- setting large rock that creates large, interstitial spaces for habitat;
- placing large woody debris to create roughness, pool and cover;

- placing large boulders in the channel to create roughness and pool habitat;
- increasing overall complexity of the bank and channel through changes in plan form; and/or
- using terracing and leaving or enhancing natural features on the upper bank.

RISK

Rock-toe treatments are similar to riprap treatments in that they provide a relatively low risk to infrastructure and reliable approach to streambank protection. Their advantage over riprap is that less non-native material is required, and there is a greater potential for habitat mitigation than strict riprap offers because it allows the upper bank to be constructed using vegetation. Rock toes with large woody debris that are not designed to be submerged can, however, pose a risk to recreational boaters and swimmers.

Habitat

Rock toes generally reduce habitat potential by hardening the bank in a relatively uniform and permanent position and shape. Additionally, they eliminate the potential for the development of undercut bank habitat, further limiting complexity and diversity along the bank. This results in lost opportunity for sediment sources and recruitment of large woody debris from eroding banks and lost potential for spawning-area development due to increased velocities along the banks. For additional discussion of impacts of rock treatments on habitat, refer to Appendix K, *Literature Review of Revetments.*

Infrastructure

Rock toes are suitable for infrastructure protection if upper-bank treatments are also designed with infrastructure protection. However, rock toes may increase the likelihood of erosion in adjacent sections of the streambank (upstream and/or downstream). This may lead to increased risk to upstream and/or downstream property owners and infrastructure.

Reliability/Uncertainty of Technique

Similar to riprap, roughened-rock toes provide a reliable approach to arresting or preventing erosion. The uncertainty of this approach stems from the corresponding uncertainty associated with upper-bank treatments that may be used in concert with rock toes.

CONSTRUCTION CONSIDERATIONS

Materials Required

Materials necessary for rock toes include angular rock, filter material (fabric or gravel) and large woody debris for mitigation and habitat components. Selection of appropriate rock materials is addressed in the design references cited in this chapter under *Riprap*.

It is important to minimizing root removal and disturbance of existing riparian trees and shrubs. Both short-term and long-term impacts to wildlife can be greatly reduced by minimizing vegetation disturbance and removal. It may be possible to build a rock toe while leaving many of the riparian trees in place. The designer and contractor will likely want the trees removed to make access and rock placement easier. However, on-site trees often can be worked around, and every effort should be made to protect them. Live trees on site should not be used for instream structures. Large woody debris should be imported from off-site sources nearby.

The creation of large voids in revetments can be avoided by using well-graded rock. However, there are biological benefits to using very large rock with correspondingly large interstitial spaces. These spaces create refuge and habitat for fish and invertebrates, and they roughen the face of the riprap. There should be a layer of smaller rock behind the large surface layer to act as an intermediate filter. Avoid pounding the rock face until it becomes smooth.

Timing Considerations

Rock toes can be installed during high-flow conditions if they are placed as launchable material. However, rock toes are best constructed during low flows, when dewatering is possible. In order to install rock to the depth of scour, excavation within the channel will be necessary and, consequently, will require temporary dewatering systems. Dewatering eases installation and prevents siltation of the stream during construction. Dewatering can be accomplished with a coffer dam during low-flow conditions.

Working in a stream during critical periods in resident and anadromous fish life cycles, such as spawning or migration, should be avoided. Instream work windows vary among fish species and streams. Contact the Washington Department of Fish and Wildlife's Area Habitat Biologist for information on work windows (see Appendix B, *Washington Department of Fish and Wildlife Contact Information*). Further discussion of construction timing and dewatering can also be found in Appendix M, *Construction Considerations*.

Cost

The cost of rock toe treatments is largely dependent upon the size of the river, which impacts the size of required rock materials and site-specific dewatering costs. Rock-toe treatments may range from $20 to $40 per foot of treatment. The cost of the associated upper-bank treatment will greatly affect overall cost. Additional cost components include dewatering and site access. Costs for these elements are discussed generally in Appendix L, *Cost of Techniques* and in Appendix M.

Essential materials include rock and filter materials. Angular rock for rock toes usually must be imported from off-site locations and varies in cost according to the source and transport distance. Rock materials typically vary from $60 to $80 per cubic yard installed. Gravel filter materials range from $40 to $60 per cubic yard if they are imported. However, the price may be more affordable if local sources are available. Filter fabric may be used as an alternative to gravel filters and ranges in price from $0.50 to $3.00 per square yard.

For further discussion of costs, refer to Appendix L.

MAINTENANCE

Maintenance needs are generally minimal if rock is sized and installed properly. Maintenance is also relatively simple and rarely requires anything more than additional rock material. Vegetation and large woody debris placed in the rock toe may require replanting or repair if they are damaged. Mitigation measures may also require maintenance.

MONITORING

Monitoring rock toe treatments is limited to survey and visual inspection, including regular photo documentation. Monitoring components should include survey and inspection of the integrity of the rock-toe treatment and monitoring of the associated upper-bank treatments. The survival rate of vegetation and anchoring success of large woody debris placed in the rock toe also needs to be monitored.

Monitoring should include detailed as-built surveying, as well as photo documentation of the project area and upstream and downstream reaches to allow for evaluation of performance relative to design. Details on development of a monitoring plan are discussed in Appendix J, *Monitoring*.

Rock-toe monitoring activities should focus on potential weak points in the design, such as transitions between undisturbed and treated banks, and between the rock toe and the upper bank. Monitoring should include a survey of the location and elevation of the rock toe at upstream and downstream limits and at 50-foot intervals along the treatment. The adjacent native soils above and behind the treatment may reveal collapse or sinking, indicative of piping loss or movement of rock materials. Additionally, monitoring should inspect for loss of rock-toe materials over time.

Monitoring frequency should be annual and should be conducted during low flows when visual inspection of the toe is possible. Additionally, monitoring should be conducted following any events that equal or exceed the one-year flow during the first three years following construction. For further discussion of monitoring methods, refer to Appendix J.

For a comprehensive review of habitat-monitoring protocols, refer to Johnson, et al.[3] Habitat-monitoring protocols will likely require a monitoring schedule that is more comprehensive than that required for the integrity of the structure.

REFERENCES

1 Peters, R. 1998. Seasonal Fish Densities Near River Banks Treated with Various Stabilization Methods. First Year Report of the Flood Technical Assistance Project. U.S. Fish and Wildlife Service. December 1998.

2 USDOT. 1989. Design of Riprap Revetment. Federal Highway Administration Hydraulic Engineering Circular, No. 11

3 Johnson, D. H., N. Pittman, E. Wilder, J. A. Silver, R. W. Plotnikoff, B. C. Mason, K. K. Jones, P. Roger, T. A. O'Neil and C. Barrett. 2001. Inventory and Monitoring of Salmon Habitat in the Pacific Northwest - Directory and Synthesis of Protocols for Management/Research and Volunteers in Washington, Oregon, Idaho, Montana, and British Columbia. Washington Department of Fish and Wildlife, Olympia, WA.

a. Roughened-Rock Toe with reinforced large woody debris and plantings. Cedar River. 1999.

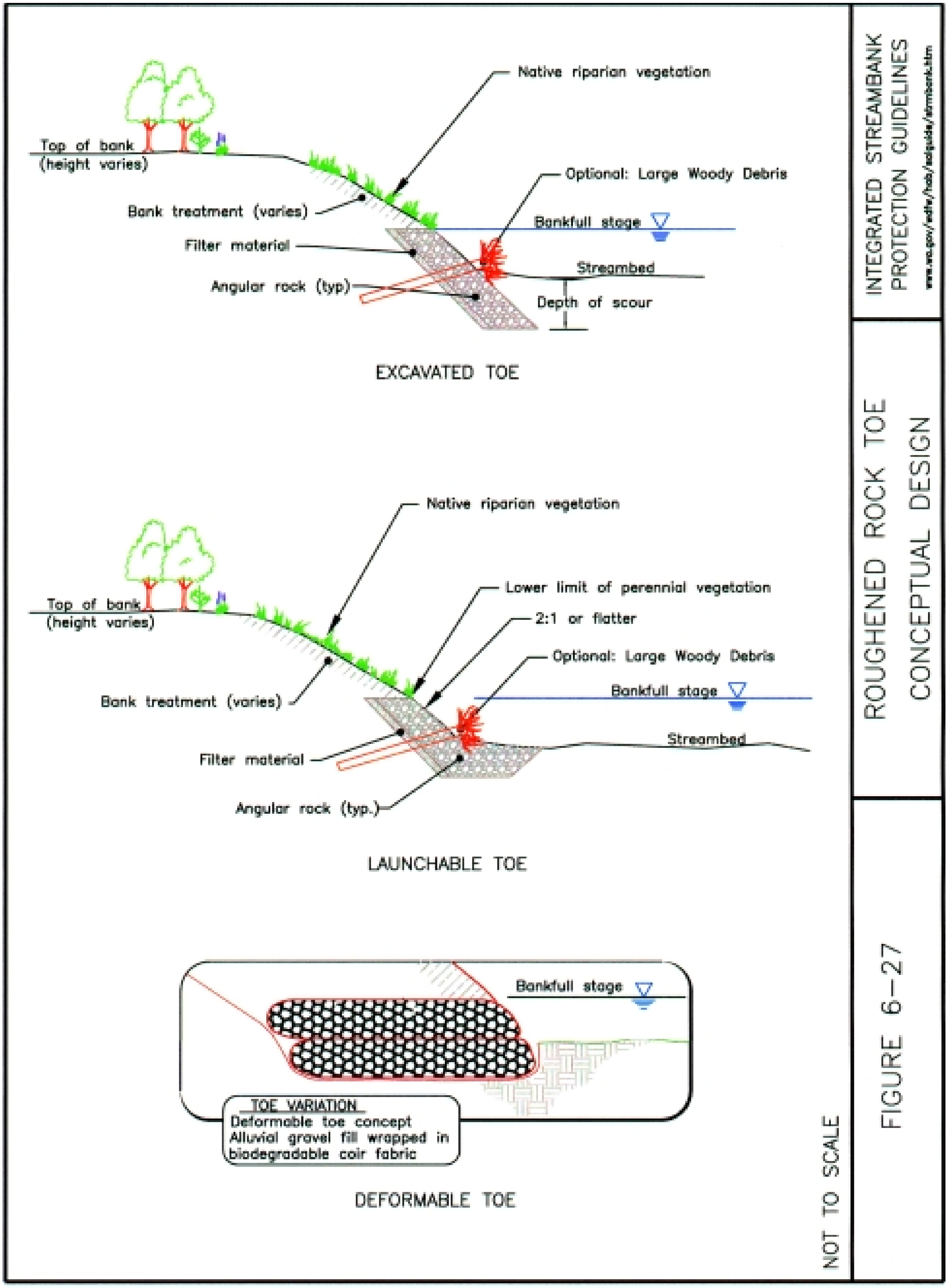
b. Roughened-Rock Toe with reinforced large woody debris, soil lifts and plantings. Nooksack River. 1999.

c. Roughened-Rock Toe with planting bench, reinforced soil lifts and plantings. Latah Creek. 2002.

d. Roughened-Rock Toe with reinforced soil lifts and plantings. Deschutes River. 1996.

e. Roughened-Rock Toe with reinforced soil lifts and plantings. Touchet River. 2000.

Figure 6-26. Various applications of roughened-rock toes throughout Washington State.



Native riparian vegetation
Top of bank
(height varies)
Optional: Large Woody Debris
Bank treatment (varies)
Bankfull stage
Filter material
Streambed
Angular rock (typ)
Depth of scour
EXCAVATED TOE
Native riparian vegetation
Lower limit of perennial vegetation
Top of bank
(height varies)
2:1 or flatter
Optional: Large Woody Debris
Bank treatment (varies)
Bankfull stage
Streambed
Filter material
Angular rock (typ.)
LAUNCHABLE TOE
Bankfull stage
TOE VARIATION
Deformable toe concept
Alluvial gravel fill wrapped in
biodegradable coir fabric
DEFORMABLE TOE
NOT TO SCALE
INTEGRATED STREAMBANK
PROTECTION GUIDELINES
ROUGHENED ROCK TOE
CONCEPTUAL DESIGN
FIGURE 6–27

DESCRIPTION

Gravity retaining walls can be useful in stabilizing streambanks. One type of gravity retaining wall is built by constructing an elongated box out of logs and backfilling the box with soils and rock. Such retaining walls are referred to as "log cribwalls." The log box is positioned with its long sides running parallel with the channel centerline and its shorter sides perpendicular to the channel centerline. The long, parallel logs are referred to as "stretchers;" and the short, perpendicular logs are called "headers." Stretchers and headers are stacked alternately to create the cribwall. Once the log cribwall is backfilled, the gaps between the successive layers of logs can serve as planting sites to create a live cribwall. *Figure 6-28* (at the end of this technique discussion) shows various applications of log cribwalls throughout Washington State.

APPLICATION

Log cribwalls are typically applied as bank protection on steep slopes. They are often installed where: 1) floodplain encroachment has occurred, and 2) a near-vertical structure is required to protect an eroding streambank. As part of construction, the existing bank is usually excavated where the cribwall will be placed to minimize channel confinement at the site.

Log cribwalls can be useful in areas where toe erosion is the predominant mechanism of failure and where structural instability results from subsurface drainage or mass failure. Refer to the screening matrices in Chapter 5, *Identify and Select Solutions* for more guidance on the applicability of log cribwalls based on the mechanism of failure and causes of streambank erosion.

Log cribwalls can also be used as toe protection where a deformable channel boundary is desirable to promote long-term channel migration and to maintain geomorphic progression. However, it should be noted that log cribwalls, by their very nature, prevent deformation - an important process in maintaining stream equilibrium and contributing material for fish habitat. Since cribwalls can last for decades, this may have a considerable impact on the stream. Refer to the segment in this chapter addressing *Log Toes* for further information regarding this application.

It is important to understand the existing physical characteristics and geomorphic processes present at both the site and along the potential project's reach (see Chapter 2, *Site Assessment* and Chapter 3, *Reach Assessment* for guidance). Log cribwalls are not recommended for use at sites where the mechanism of failure is an avulsion or local scour. Log cribwalls are also not recommended for use within aggrading or rapidly degrading reaches.

Emergency

Log cribwalls are not recommended for use as an emergency bank-protection technique because they require time to design, and construction is difficult and impractical during high-flow events.

EFFECTS

Log cribwalls can be very effective at controlling bank erosion and can provide relatively permanent protection. However, permanent protection eliminates a source of sediment supply and recruitment of large woody debris, which affects the natural balance of erosion and deposition within a channel. Also, cribwalls tend to arrest downstream meander migration, increasing bank erosion upstream and/or downstream from their placement. Because logs have a limited life span, this effect is not permanent, but it may go on for decades.

The reduced roughness characteristics of log cribwalls may also have a detrimental impact to adjacent spawning beds, cover and holding habitat. Roughness can be enhanced in the design of a log cribwall by densely planting the gaps in the cribwall and/or incorporating roughness elements such as rootwads into the cribwall's construction.

Log cribwalls also cause increased velocity and reduced complexity and diversity along the channel margin, thereby affecting habitat value, though considerably less so than riprap treatments do. The increased velocity may also cause the channel to deepen at the toe, concentrating the thalweg (deepest part of the channel) along the log cribwall bankline. These effects can be mitigated, to some degree, by incorporating rootwads or large woody debris in the treatment. The vertical nature of cribwalls make them somewhat comparable to bridge abutments, and studies have shown that vertical bridge abutments incur twice the scour that sloped abutments do. Additional scour is likely if rootwads are incorporated into a log-cribwall design due to exaggerated turbulence around them. Scour depth must be anticipated so that the log-cribwall treatment is installed deep enough not to be undermined. Therefore, scour must be accounted for in both the depth of the toe and in armoring the adjacent banks. For a more extensive discussion of the effects of log cribwalls on river morphology and aquatic habitat, see Appendix K, *Literature Review of Revetments*.

DESIGN

Design of log cribwalls includes geotechnical, structural and biological analysis. The integrity and safety of a log cribwall structure cannot be provided without specific geotechnical and structural analysis. For this reason, it is very important that qualified structural and geotechnical engineers be included as part of the design team. A conceptual design drawing is shown in *Figure 6-29*.

Geotechnical Considerations

Since a log cribwall functions as a gravity retaining wall, it should be designed in such a way as to resist sliding, overturning and bearing failure. Additional aspects that must be taken into consideration in design include: deep-seated shear, existing and proposed hydraulic conditions, transitions from the ends of the cribwall to the undisturbed streambank, backfill retention, structural integrity of the crib, plant establishment and design life. The following guidance will assist in taking these factors into account in the design phase; however, additional useful information can be found in Donald Coduto's book, *Foundation Design, Principles and Practices.*[1]

Designing *resistance to sliding* into the treatment involves calculating active and passive lateral earth pressures applied by adjacent soils and comparing them to the log cribwall's frictional resistance to sliding. The log cribwall's resistance to sliding may be improved by increasing its footprint, mass and/or inclining the log cribwall with a batter angle.

Resistance to overturning can be achieved by calculating movements applied by active and passive lateral earth pressures and comparing them to the log cribwall's ability to resist those moments. The log cribwall's ability to resist overturning may be increased by increasing its footprint and/or mass, and/or by inclining the log cribwall with a batter angle.

Underlying soils must be able to support the cribwall without settling. In other words, they must be able to *resist bearing failure*. A geotechnical analysis is suggested to determine the bearing capacity of the soil. If the soil has a low load-bearing capacity, the log cribwall's foundation soils should be replaced; a pile foundation should be driven to transmit the load to lower layers of soils, and/or its mass should be decreased.

Deep-seated shear failure refers to a rotational failure of soils behind and underneath the log cribwall. Deep-seated shear failure is a rare but catastrophic event. A geotechnical engineer will look at ways to resist deep-seated failure by first analyzing lateral earth pressures and the cribwall's resistance to sliding, overturning and bearing failure. He or she will then assess the likelihood of a global rotational failure or deep-seated shear failure. Log cribwalls are semi-flexible systems (compared to riprap, which is flexible, and concrete, which is inflexible), which may enable them to compensate for small movements behind the structure.

Hydraulic Conditions

Existing and proposed hydraulic conditions are discussed in the earlier section of this technique discussion under *Effects*. The designer should avoid the creation of channel constrictions when determining the placement for cribwalls. A scour analysis should be performed, and the log cribwall should be extended below the anticipated depth of scour. For further discussion on calculating scour, refer to Appendix E, *Hydraulics*.

Transition

Depending upon site and reach conditions, it may be necessary to create a smooth transition at the upstream and downstream ends of the log cribwall, especially if adjacent streambank soils are erodible. If a smooth transition is not created, turbulent eddies will result, and erosion may occur upstream or downstream of the cribwall. Installing a key into the banks may be necessary at the ends or the cribwall to resist flanking of the structure. For further information about keying treatments at the upstream and downstream end, refer to the discussion in this chapter regarding the technique, *Riprap*.

Backfill

A log cribwall must retain its backfill in order to maintain its integrity as a gravity retaining wall. Care must be taken to avoid loss of backfill through the gaps between logs comprising the cribwall. This may be accomplished by using a granular filter, where coarse backfill material spans the gaps along the structure's face and by using progressively finer material within the cribwall. The coarse backfill material at the structure's face should be of a quality suitable to serve as productive growing medium for live cribwalls.

Structural Integrity

The structural integrity of a log cribwall depends upon the size and strength of its log members and the method of fastening headers and stretchers together. To learn more about selecting the correct size of logs, review the American Institute of *Timber Construction's Timber Construction Manual; A Manual for Architects, Engineers, Contractors, Laminators, and Fabricators Concerned with Engineered Timber Buildings and Other Structures*.[2] Log cribwalls should be constructed using logs that retain their strength for an acceptable period of time and are resistant to rot. Cedar and spruce logs provide a relatively good resistance to rot, while soft wood, such as alder and pine, should be avoided. The use of galvanized fasteners, which include spikes and lag bolts, must be of a size large enough to withstand forces applied by internal cribwall stresses. For further information, refer to Appendix I, *Anchoring and Placement of Large Woody Debris.*

Vegetation

The greatest challenge for designing live cribwalls is providing a suitable growing medium. Cribwall backfill must be fine enough to retain moisture so that plants can grow. However, fine backfill is more likely to be washed through the gaps between cribwall members. A granular filter or biodegradable erosion-control fabrics may be used to reduce soil loss. Cribwall backfill must also have enough organic content to provide nutrients to plants placed within live cribwalls. Live cribwalls may require irrigation, and plant selection should be based upon the frequency and duration of inundation. See Appendix H, *Planting Considerations and Erosion-Control Fabrics* for more information. Woody plants placed in live cribwalls may extend the longevity of a log cribwall; as their root systems become more extensive, they can provide the stability that would otherwise be lost as log crib members rot over time.

BIOLOGICAL CONSIDERATIONS

Mitigation Requirements for the Technique

Placing log cribwalls may require removal of existing riparian vegetation. Constructing a live cribwall serves as mitigation for this loss. Plant root structures can continue to provide bank stability after the log cribwall members decay. Additionally, planting a riparian buffer adjacent to the treatment will provide long-term erosion protection as the log cribwall eventually degrades.

Other requirements may include mitigation for lost-opportunity impacts and loss of cover, complexity and diversity. Construction impacts will also require mitigation.

Habitat loss can be partially mitigated by creating hydraulic roughness along a cribwall to provide more complex habitat. Embedding rootwads beneath or within log cribwalls can provide flow breaks and eddies that are used by fish. Rootwads can be placed beneath the cribwall with the root ball extended into the active channel. Another method to incorporate rootwads and enhanced roughness characteristics is to use them for headers in the cribwall, where root balls are extended into the active channel. For further information about design considerations for incorporation of large woody debris, refer to Appendix I. Refer to Chapter 4, *Considerations for a Solution* for further discussion of mitigation requirements and to Matrix 3 in Chapter 5 for more detail on mitigation needs for this bank treatment.

Mitigation Benefits Provided by the Technique

A live cribwall may eventually provide shade to a stream, thus providing a water-quality benefit. Live cribwalls provide overhanging cover for enhanced fish habitat. Rootwads attached to the toe logs provide cover and interstitial flow breaks for holding habitat. Also, a log cribwall can serve as a temporary template structure for restoring natural channel processes. Log cribwalls provide interim soil stability to allow streambank vegetation to become established. Riparian vegetation provides stability after log cribwall members decay and allows natural meander migration processes to occur.

RISK

The log cribwall treatments themselves provide a relatively low risk and reliable approach to streambank protection. However, if rootwads are a component of the design, then their potential hazard to recreational users should be evaluated prior to implementation.

Habitat

A smooth cribwall may cause scour and bury spawning beds adjacent to and/or downstream of the site. Other potential risks include temporary loss of cover and holding habitat due to reduction of roughness characteristics.

Log cribwalls result in lost opportunity for sediment supply, recruitment of woody debris and off-channel spawning and rearing habitat by locking a streambank in place. Such lost opportunity will need to be mitigated. The duration of lost opportunity can be up to decades long, depending upon factors such as type of logs used in the cribwall, size of logs, duration of submersion and flow characteristics of the stream. For further discussion of lost opportunity, refer to Chapter 4.

Infrastructure

Log cribwalls depend on the strength of their wood members to reinforce soils and support steep slopes. The logs used to construct such cribwalls will eventually rot and lose their strength. Plants established within a live cribwall may or may not provide enough strength to reinforce soils as log crib members rot. For this reason, there is uncertain risk of damage to adjacent infrastructure where log cribwalls have been installed. The designer should compare the design life of the infrastructure to be protected with the anticipated design life of the log cribwall and eventual establishment of riparian vegetation. The design life of the log cribwall may be maximized by using logs that are resistant to rot, joining crib members with galvanized fasteners and planting woody vegetation within the log cribwall structure. In most cases, a properly designed log cribwall should outlast the design life of the infrastructure to be protected.

Reliability/Uncertainty of Technique

If vegetation becomes established, and rooting depth and density is sufficient to reinforce soils after log crib members rot, a live cribwall can become a semi-permanent structure. However, vegetation may die before it becomes established, or rooting depth and density may not become sufficient enough to reinforce soils before log crib members rot. This uncertainty can be minimized by planting vegetation densely and by providing it with adequate nutrients, sunlight and water. Monitoring vegetation through its establishment period is also important in minimizing uncertainty.

CONSTRUCTION CONSIDERATIONS

Materials Required

The market demand for wood products can provide challenges when trying to obtain logs for cribwalls. However, log cribwall structures do not generally require large-diameter logs; they can be constructed from logs ranging in diameter from six inches to 18 inches, depending upon strength of wood and stream hydraulics.

Sediment- and erosion-control materials, fasteners and backfill are also required for log cribwalls. Refer to Appendix I for further discussion of anchoring wood. Live cribwalls also need vegetation to be planted in them in order for them to be effective (see Appendix H). A common type of plant material used consists of riparian cuttings obtained from native, woody vegetation.

Timing Considerations

Cribwalls are best constructed during low flow, when dewatering is possible. Dewatering eases installation and prevents siltation of the stream during construction. This can be accomplished using a coffer dam during low-flow conditions.

Log cribwalls should be constructed to minimize instream disturbance. Instream work windows vary among fish species and streams. Contact the Washington Department of Fish and Wildlife's Area Habitat Biologist for information on work windows (see Appendix B, *Washington Department of Fish and Wildlife Contact Information*). Further discussion of construction timing and dewatering can also be found in Appendix M, *Construction Considerations*.

Vegetation will have a better chance of surviving transplant to the live cribwall if cuttings are collected in the winter months when the vegetation is dormant. Typically, cribwalls are most successfully constructed in the summer months, so planning and acquisition of vegetation may need to be done well in advance of the actual construction. After the cuttings are collected, they must be kept dormant in cold storage until construction begins, or be sprouted and cared for in a nursery until they can be planted in the cribwall.

Cost

Construction of log cribwalls involves excavation, installation of the crib structure, backfilling and installation of vegetation. Typical costs range from $250 to $350 per foot of bank protected. Costs are greatly affected by availability of log materials, labor rates, and dewatering needs. Logs used for cribwall construction must be relatively straight and comparable in diameter. Refer to Appendix L, *Cost of Techniques* for further discussion of costs associated with materials acquisition and site dewatering.

MAINTENANCE

Maintenance may include repairing log members and anchors, or looking after the vegetation in the structure. Establishment of vegetation may require irrigation during the first-year growing season. Maintenance of live cribwalls should also include replacing dead vegetation if it is an integral part of the cribwall's structural integrity.

MONITORING

Monitoring of log cribwall treatments should include survey and inspection of the integrity of the log-cribwall structure and associated vegetation components. Monitoring should also include detailed, as-built surveying and photo documentation of the project area, and upstream and downstream reaches to evaluate design performance. Details on how to develop a monitoring plan are discussed in Appendix J, *Monitoring*.

Survey and visual inspection, as well as photo documentation, should focus on:

- scour at the toe of the cribwall structure,
- subsidence of backfilled soils,
- plant-growth progress,
- evidence of erosion adjacent to the log cribwall,
- potential weak points in the design (such as transitions between treated banks and undisturbed upstream and downstream banks),
- location and elevation of key log members at 50-foot intervals along the treatment and at upstream and downstream limits,
- sagging or movement of log members,
- loss of logs, and
- deterioration of logs.

Monitoring frequency should be annual for at least the first five years (or the anticipated design life of the structure if less than five years) and conducted during low flows when visual inspection of the toe of the structure is possible. Additionally, monitoring should be conducted following any events that equal or exceed the one-year flow during the first three years following construction. For further discussion of monitoring methods, refer to Appendix J.

For a comprehensive review of habitat monitoring protocols, refer to Johnson, et al.[3] Habitat-monitoring protocols will likely require a monitoring schedule that is more comprehensive than that required for the integrity of the structure.

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2 American Institute of Timber Construction, Timber Construction Manual; A Manual for Architects, Engineers, Contractors, Laminators, and Fabricators Concerned with Engineered Timber Buildings and Other Structures, New York, Wiley, 1974.

3 Johnson, D. H., N. Pittman, E. Wilder, J. A. Silver, R. W. Plotnikoff, B. C. Mason, K. K. Jones, P. Roger, T. A. O'Neil and C. Barrett. 2001. Inventory and Monitoring of Salmon Habitat in the Pacific Northwest - Directory and Synthesis of Protocols for Management/Research and Volunteers in Washington, Oregon, Idaho, Montana, and British Columbia. Washington Department of Fish and Wildlife, Olympia, WA.

a. Log Cribwall during construction. Columbia River.
Source: Inter-Fluve, Inc.

b. Log Cribwall. Fanno Creek, OR.
Source: Inter-Fluve, Inc.

Figure 6-28. Examples of log cribwalls throughout Washington State.

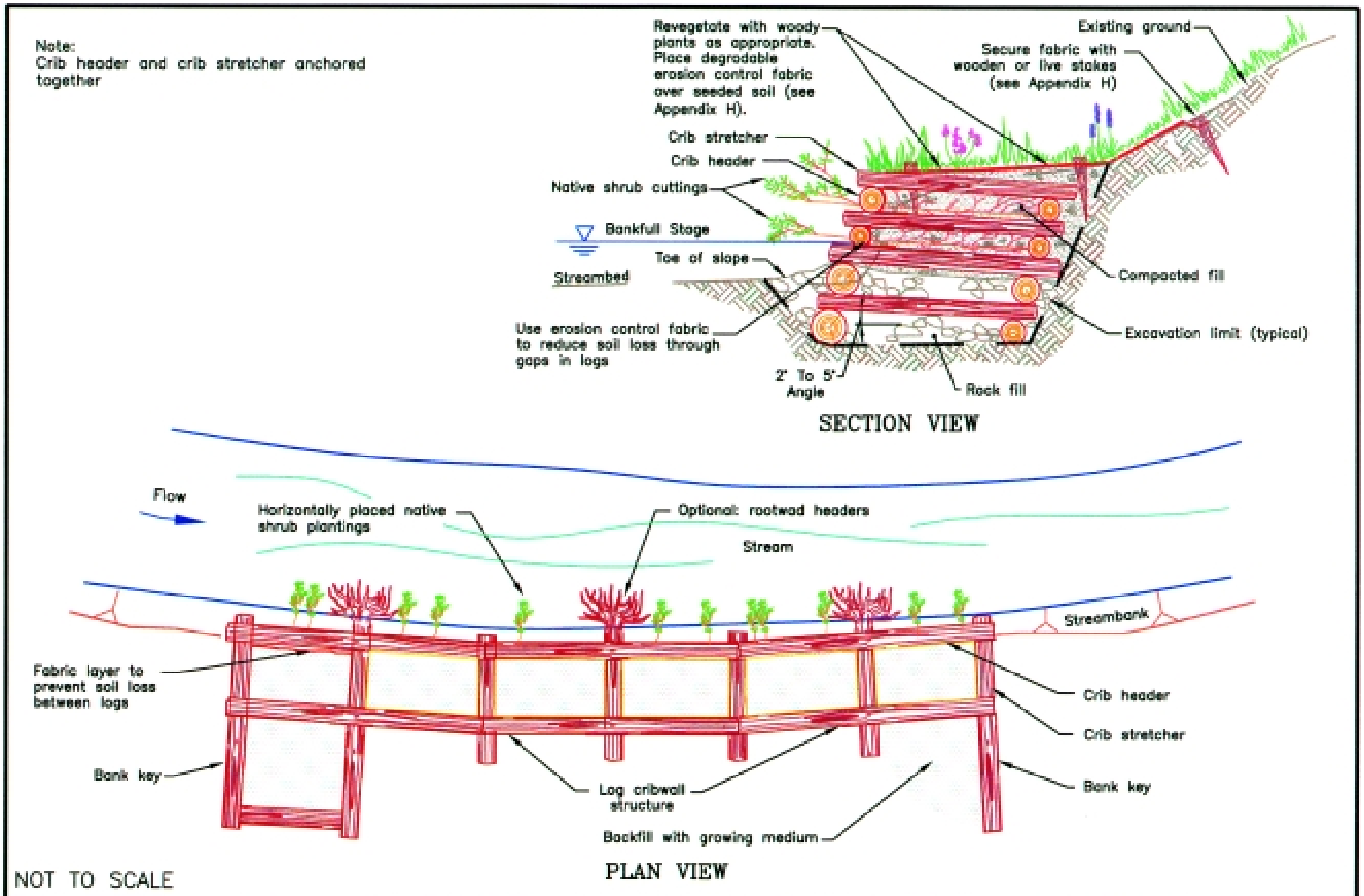

FIGURE 6–29

LOG CRIBWALL CONCEPTUAL DESIGN

INTEGRATED STREAMBANK PROTECTION GUIDELINES
www.wa.gov/wdfw/hab/ahg/strmbank.htm

DESCRIPTION

Manufactured retention systems can be used to stabilize channel banks and beds. There are a large variety of systems available, with more appearing on the market each year. For the purposes of discussion, these retention systems are classified into two categories, based on material type: two-dimensional and three-dimensional. Two-dimensional retention systems provide relatively thin, skin-like protection to bank surfaces and include a variety of fabrics, reinforcement mats and geogrids. Three-dimensional retention systems provide a relatively thick, durable outer layer and include articulated concrete blocks, geocellular containment systems, concrete armor units and wire-mesh walls.[1] Systems within these categories (except wire-mesh walls, which will be discussed in future editions of these guidelines) are briefly described below (the Washington Department of Fish and Wildlife does not recommend or endorse any one product or trade name). *Figure 6-30* (at the end of this technique dicussion) shows applications of these systems.

Two-Dimensional Retention Systems

Fabrics and Reinforcement Mats

Fabrics and reinforcement mats are mainly used as temporary surface protection to lend tensile strength and shear resistance and to retain soil particles on the surfaces of streambanks and floodplain areas until vegetation gets established. These products come in biodegradable, nonbiodegradable and composite (semi-biodegradable) form. Biodegradable materials used in fabric and mat construction commonly include coir (coconut fiber), jute, straw and cotton mesh. Nonbiodegradable fabrics and mats are generally constructed of UV-stabilized synthetic fibers, such as polypropylene, Tensar or nylon.

The difference between fabrics and reinforcement mats can be subtle and somewhat subjective. Fabrics are woven materials of marginal thickness used as an outer "skin" atop the soil surface. Most fabrics are sufficiently porous to allow vegetation to readily establish through them. Reinforcement mats typically are thicker and more porous than fabrics and are usually not woven. Reinforcement mats are intended to become an integral component of the slope surface. In fact, soil is often installed on top of mats and worked into the voids within the mats to facilitate incorporation into the seeded turf.

Fabrics and reinforcement mats are available in a variety of materials, configurations, strengths and levels of biodegradability. Available products range from light-duty, completely biodegradable, erosion-control blankets of straw and cotton mesh to very-heavy-duty reinforcement mats constructed of nonbiodegradable, UV-stabilized polypropylene. The most durable of such products can be used as a long-lasting alternative to riprap. The least durable serve only as temporary protection against surface erosion caused by rainfall.

Geogrids

Geogrids are grids made of a UV-stable, high-strength, synthetic material. Originally developed for use as an internal-stabilization tool for embankments, geogrids are also used to impart tensile strength to the surface of constructed streambanks and other instream structures. To provide internal stabilization to embankments and streambanks, the geogrid is usually laid horizontally in the bank materials to protect against translational and rotational slope failure. As a surface treatment, geogrid is used to encapsulate soil and/or rock on the bank surface. Geogrid offers a very durable and high-strength skin to the constructed bank. Its porous construction also allows vegetation to establish itself. Because the holes in geogrid are relatively large, an inner layer of fabric or reinforcement mat should be used to prevent soil loss.

Three-Dimensional Retention Systems

Articulated Concrete Blocks

Articulated concrete blocks are precast concrete blocks held together by interlocking edges, steel or synthetic fiber cables, or a combination of the two. There are currently a variety of these products available that are well suited for a wide range of applications. The heavy-duty blocks are over nine inches thick, have no holes within the blocks for vegetation and are held together with steel or synthetic fiber cables. Lighter-duty blocks are also held together by cables, but have holes for inter-planting of vegetation. The lightest-duty blocks are held together solely by their interlocking edges and are available with or without holes for vegetation.

Articulated concrete blocks represent a flexible and very durable bank treatment similar to riprap. Like riprap, articulated concrete blocks generally require a filter layer of granular material, filter fabric or both, placed between the block layer and underlying native soil. As in the case of riprap, these blocks offer very little aquatic or terrestrial habitat, although holes in most types of blocks allow for the installation of soil and vegetation. Common locations where articulated concrete blocks have been used successfully are under bridges for slope protection to protect abutments.

Geocellular Containment Systems

Geocellular containment systems are honeycomb-like cellular materials that stabilize the upper layer of soil, while allowing installation of soil and vegetation. Usually manufactured of polyethylene or polyester strips, the thin-walled cells can be up to 20 centimeters (about eight inches) deep.[1] Because the walls of the geocellular "honeycomb" are relatively thin, vegetation and soil make up the vast majority of geocell volume.

Geocellular containment systems provide substantial structural support to the bank face, while allowing vegetation to establish almost unimpeded. On gently sloping banks, geocellular containment systems can be installed directly on the bank slope, at the same grade as the bank face. On steeper banks, the geocellular containment system can be installed in a stair-step fashion for greater stability. To further increase slope stability, an internal drain of granular material and filter fabric are often installed beneath the geocellular containment systems.

Concrete Armor Units

Concrete armor units include a wide variety of three-dimensional products constructed of reinforced concrete. They are typically installed as a layer on streambanks and around bridge abutments. Originally designed for use in coastal engineering, these structures have been used in river engineering to provide scour protection near structures, toe protection for banks, and barbs. Concrete armor units are available in a number of configurations under such product names as Doloes, Toskanes and A-Jacks®. They range in size from relatively small, hand-installed A-Jacks® to eight-ton Doloes. Some products, such as A-Jacks®, are available in a variety of sizes.

Reinforced Wire Wall

Manufactured retention systems can be used to stabilize channel banks and beds. There are a large variety of systems available, with more appearing on the market each year. For the purposes of discussion, these retention systems are classified into two categories, based on material type: two-dimensional and three-dimensional. Two-dimensional retention systems provide relatively thin, skin-like protection to bank surfaces and include a variety of fabrics, reinforcement mats and geogrids. Three-dimensional retention systems provide a relatively thick, durable outer layer and include articulated concrete blocks, geocellular containment systems, concrete armor units, and reinforced wire walls.[1] Systems within these categories are briefly described in the next section (the Washington Department of Fish and Wildlife does not recommend or endorse any one product or trade name). Reinforced wire walls are not described in this edition of the guidelines but will be in the next edition.

APPLICATION

Manufactured retention systems are appropriate for sites where the mechanism of failure is mass failure or subsurface entrainment. They are also appropriate for armoring against all types of scour if applied landward of the scour hole. Artificial materials and systems are not appropriate for sites where there exists the potential for an avulsion or for meander migration within the channel migration zone. They are also not appropriate for toe erosion caused by a reduced-vegetative bank structure or a smoothed channel.

Refer to Chapters 2, *Site Assessment* and 3, *Reach Assessment* for further discussion of site and reach limitations, and to Chapter 5, *Identify and Select Solutions* for further discussion of appropriate selection of protection techniques.

Fabrics and Reinforcement Mats

Fabrics and reinforcement mats are typically used where the stream flow is relatively low in energy and there is a good revegetation potential. Biodegradable materials typically provide temporary support for three to five years. Most stream and river banks (at least the upper portions) meet these criteria. Fabrics and reinforcement mats should not be used below the line of perennial vegetation nor anywhere that conditions such as hydraulic forces or shade are likely to preclude dense vegetation growth.

For more information on fabric and reinforcement mat installation, refer to Appendix H, *Planting Considerations and Erosion-Control Fabrics*.

Geogrid

There are two common uses for geogrid in streambank construction. Geogrid is sometimes used like a fabric or reinforcement mat in lift construction (see the discussion in this chapter on *Soil Reinforcement*). Used as such, geogrid provides a highly durable, high tensile-strength outer layer that allows for vegetation growth. Geogrid is more widely used to provide internal stability to slopes and embankments. In this capacity, geogrid protects against translational and rotational slope failure.

Articulated Concrete Blocks

Articulated concrete blocks are usually used where stream flow is high-energy and where bank failure is not acceptable, such as under bridge abutments. Typically, blocks without holes are used below the line of perennial vegetation. Above that line, blocks with holes that allow planting are recommended. The articulated-concrete-block revetment system usually requires a filtering under layer to prevent fine bank material from migrating into the block layer, a situation that can threaten bank stability. Articulated-concrete-block revetment typically results in an extremely uniform bank surface, a factor that should be considered when habitat and aesthetic values are important. In addition, the smooth surface of revetment will result in relatively high velocities along the streambank.

Geocellular Containment Systems

Geocellular containment systems are suitable for use in low- to medium-energy-flow situations. On gently sloping streambanks, the cellular systems can be laid at the grade of the bank, staked and filled with soil, and seeded. On steeper banks, the cellular systems can be laid in the horizontal plane and stepped to produce a relatively steep bank. Including a fabric outer layer helps retain soil in the individual cells. Such stepped cellular systems have been used in conjunction with geogrid to stabilize relatively high, steep banks under rapid drawdown situations.

Concrete Armor Units

Concrete armor units have been successfully used to stabilize eroding banks, to counteract scour at bridge piers and abutments, and to construct barbs and groins. In addition, concrete armor units can be used to anchor log jams. As components of bank protection, concrete armor units create a large amount of void space, which may be useful as aquatic and terrestrial habitat. In addition, groins constructed of these units tend to be very effective collectors of woody debris.

For the majority of materials discussed in this section, vegetation provides some or all of the long-term strength. Vegetation stabilizes bank surfaces in a variety of ways: roots provide deep and shallow stability to the bank soil, protecting against surface erosion and slope failure; and stems and leaves provide roughness to protect the bank surface from runoff above the water line at low flows. At higher flows, stems and leaves also create a low-velocity boundary layer near the bank surface. Because dense vegetation is a desirable (and sometimes required) component of most manufactured retention systems, these systems are generally applicable only to the zone lying above the line of perennial vegetation growth. Exceptions to this generalization include articulated concrete blocks and concrete armor units, which do not rely on vegetation for their function.

Bank protection below the line of perennial-vegetation growth requires materials and techniques that retain their long-term viability independent of vegetation cover. This lower portion of the bank is typically referred to as the bank toe. Materials commonly used to construct the bank toe include rock; coir log; gravel-filled, reinforced lift; and wood. Less-common materials include articulated concrete blocks and concrete armor units. A common bank-treatment strategy involves combining a constructed bank toe with an upper bank that is reinforced with fabric, reinforcement mat, or similar materials. This strategy provides durable protection against scour at the bank toe, coupled with readily vegetated upper-bank surfaces.

VARIATIONS

All of the manufactured retention systems discussed in this section can be combined to address specific situations. For instance, a composite bank treatment might include an articulated-concrete-block bank toe, a midbank of stepped geocellular materials and an upper bank of fabric-encapsulated soil.

It is highly recommended that vegetation be incorporated into all bank revetment designs. Proven revegetation strategies include seeding, sod installation, willow cutting installation and planting of container-grown plants. Planted vegetation should always be native species.

EMERGENCY

With one exception, installation of the manufactured retention systems discussed in this section require dewatered conditions. Additionally, installation tends to be relatively labor-intensive and time-consuming. For these reasons, the manufactured retention systems discussed in this section are not particularly suitable for emergency installation. The exception, concrete armor units, can be installed under somewhat adverse conditions. However, unlike emergency bank-protection measures that do not require precision (such as riprap, which can simply be dumped into place), concrete armor units must be set in place one-by-one using a crane or excavator.

COMPONENTS

Manufactured retention systems typically contain some or all of the following components: outer layer, under layer, securing system and internal slope support. In addition, vegetation lends strength to some systems and habitat/aesthetic value to others.

Outer layer

Outer-layer materials include fabrics, retention mats, geogrid, geocellular containment systems, articulated concrete blocks or concrete armor units. The outer layer is in direct contact with the stream flow and is, therefore, subjected to direct hydraulic forces as well as vibration, abrasion and debris impact. In the case of fabrics, retention mats and geogrid, the tensile strength of the outer layer often contributes to slope stability. The outer layer should, therefore, be selected and designed to withstand all anticipated shear forces in accordance with the project-design criteria.

Under layer

Depending upon the nature of the outer layer, the under layer may provide filtration of fine particles, drainage or growth medium. Fabrics, retention mats and geogrid (when used as a surface treatment) typically require an under layer of soil to support vegetation growth. In geocellular containment systems, the soil can be considered to be an integral part of the outer layer.

Articulated concrete blocks and concrete armor units generally require a filtering under layer to prevent the migration of fine particles from the underlying streambank soil. If not properly addressed, this migration of fine particles can lead to the formation of voids in the underlying soil, which may destabilize the bank.

Streambanks that are relatively high, steep, composed of poorly draining soils or any combination therein often require a subsurface drainage system. Subsurface drains are typically composed of granular material such as crushed gravel, but can also be constructed of synthetic drain materials or a combination of natural and synthetic materials (see the discussion in this chapter addressing *Subsurface Drainage Systems* for additional information). The draining under layer relieves soil-pore pressure within the bank, improving bank stability. This is particularly important when banks are high, steep or subject to rapid drawdown. In practice, a draining under layer can usually be designed to serve as a filtering under layer as well.

Securing System

With the exception of concrete armor units, all materials described in this section must be secured to the bank surface. Since edges and joints between materials are potential weak points, proper design of the overlap and anchoring system is critical to revetment integrity.

Fabrics, retention mats, geogrid and geocellular containment systems are typically secured by staking. However, vegetation can provide additional anchoring strength. Often, 24-inch-long wood stakes are used in conjunction with key trenches to form a stronger anchor. Articulated concrete blocks are usually secured by trenching and cabling them to deadmen along the outer edge of the revetment.

Internal Slope Support

Occasionally, special precautions must be made to ensure internal stability of streambanks. As is the case for subsurface drainage systems, internal supports are generally needed for banks that are high, steep, poorly-drained, or any combination therein. Two commonly used methods of internal support include geogrid and geocellular containment systems. When used in a "stepped" configuration, geocellular containment systems lend support to the outer portion of the bank. Geogrid is commonly used to provide deeper internal slope support. Geogrid has become popular for use in the stabilization of hill slopes and embankments along highways.

Vegetation

Vegetation contributes habitat value, aesthetic appeal and strength to bank surfaces. Some retention systems, such as articulated concrete blocks and concrete armor units, employ vegetation strictly for habitat and aesthetic values. Other systems, such as geocellular containment systems and nonbiodegradable retention mats, employ vegetation to bolster long-term resistance to erosion. Systems constructed of biodegradable materials typically rely entirely on vegetation to provide long-term slope stability and resistance to erosion.

EFFECTS

Effects vary according to the combinations of manufactured retention systems employed and by the efforts taken to create aquatic and terrestrial habitat. Systems discussed in this section can be used to construct uniform banks offering little habitat value of any kind, more natural-looking streambanks that are heavily vegetated with native riparian plants or any variation in between.

Generally, biodegradable, two-dimensional systems offer the greatest potential for promoting habitat value and minimizing mitigation requirements. Deformable bank treatments generally incorporate these materials. Conversely, nondegradeable, three-dimensional materials eliminate the opportunity for sediment and large-woody-debris recruitment, will require significant mitigation and should, therefore, only be used where relatively permanent and nondeformable protection is needed.

DESIGN

Engineering analysis for streambank design requires examining hydraulic forces, slope stability and filtration and drainage concerns. Determination of hydraulic forces typically involves using Manning's equation (see Appendix D, *Hydrology*) to estimate parameters, such as channel depth, velocity and wetted perimeter. From these parameters, shear is calculated. Factors such as the increase in shear and velocity on the outside of bends should always be considered in the hydraulic analysis (see Appendix D and Appendix E, *Hydraulics*). Available design guidelines from manufacturers of retention materials should be consulted for specific design criteria.

The correct choice of manufactured retention systems depends upon the circumstances of the site and project, including :

- project objectives;
- acceptable risk of failure;
- acceptable types of materials (e.g., biodegradable vs. nonbiodegradable);
- magnitude of hydraulic forces at the site;
- soils and slope stability concerns; and
- potential for vegetation to establish.

The choice of materials, their grade or weight, and their securing system are typically based on anticipated velocity and shear. Most manufacturers of retention systems offer material testing results and durability information for use as design guidelines. When using these systems, the designer should consider the conditions under which the tests were performed. For instance, materials are often tested for shear resistance over relatively brief time periods, whereas the same materials in an actual bank revetment may be subjected to prolonged exposure to shear on a yearly basis. The designer should consider using a factor of safety of 1.5 to 2.5.

Filter

Methods for determining the need for and design of a filtering under layer are presented in most riprap-design manuals. Refer to the discussion in this chapter entitled, *Riprap* for additional information and sources of information about filter materials. In addition, most manufacturers of articulated concrete block units provide guidelines for filter-layer design.

Vegetation

In general it is recommended that manufactured retention systems be revegetated aggressively. In addition to providing critical strength to some retention systems, vegetation provides terrestrial habitat as well as shade, overhanging cover and nutrient input to the adjacent stream or river. Revegetation can be accomplished by installing seed, sod, cuttings and container-grown or transplanted plants. Refer to Appendix H for more information on revegetation and erosion control.

BIOLOGICAL CONSIDERATIONS

Mitigation Requirements for the Technique

Application of manufactured retention can range from relatively barren, uniform streambanks to heavily vegetated, natural-looking streambanks. An aggressive revegetation effort is required for banks constructed of manufactured retention materials. If revegetation is thorough and successful, most of the materials and techniques presented in this section will result in banks requiring no mitigation for riparian habitat. However, any bank treatment constructed as nondeformable will likely require mitigation for lost opportunity, riparian function, cover, spawning, complexity and diversity, construction, and flood refuge.

The heavier bank treatments, which include articulated concrete blocks and concrete armor units, are the most likely to require mitigation for habitat loss and opportunity lost for sediment and large-woody-debris recruitment. On-site mitigation strategies such as extensive planting (including installation of cuttings amongst concrete armor units) can be used to hide these concrete treatments from view and provide terrestrial habitat. In addition, large woody debris can be added to these treatments (see Appendix I, *Anchoring and Placement of Large Woody Debris*). Due to the limitations of on-site mitigation for articulated-concrete-block and concrete-armor-unit revetments, off-site mitigation may be required. Refer to Chapter 4, *Considerations for a Solution* for further discussion of mitigation requirements and Matrix 3 in Chapter 5 for more detail on mitigation needs for this bank treatment.

Mitigation Benefits Provided by the Technique

No mitigation benefits are provided by these techniques.

RISK

Habitat

With proper application, manufactured retention systems can provide terrestrial habitat in the region of the banks lying above the line of perennial vegetation. However, risks to habitat are present. For instance, a uniform bank toe offers poor aquatic habitat and increases velocities, which, in turn, limits spawning potential. Additionally, inadequate or unsuccessful revegetation efforts can result in poor upper-bank habitat; this is particularly likely with articulated-concrete-block or concrete-armor-unit revetments.

The risk to aquatic habitat along the bank toe can be minimized by installation of large woody debris as a component of the bank toe (see Appendix I). The risk of creating inadequate upper-bank habitat can be minimized by a well-planned and well-carried-out revegetation plan, by replanting as necessary and by avoiding the use of articulated concrete blocks and concrete armor units as upper-bank treatment wherever possible.

Infrastructure

The improper use of manufactured retention systems, or their use at an inappropriate location, could lead to bank failure that results in damage to infrastructure. However, the application of harder, three-dimensional treatments can reduce risk to adjacent infrastructure.

Reliability/Uncertainty of Technique

In general, the application of manufactured retention materials and systems carries a higher level of uncertainty than traditional bank treatments like riprap. This is primarily due to the relative complexity of the systems, uncertainties regarding in-situ material strength and longevity, and the reliance of many systems on relatively rapid and dense vegetation establishment. Nonetheless, when used properly, manufactured retention materials and systems have been effective.

CONSTRUCTION CONSIDERATIONS

Materials Required

The various materials and applications presented within the category of *Manufactured Retention Systems* will require a respective variety of construction considerations. However, installation of all of these materials and systems will require consideration of access to the site for equipment and materials. Further information on access and dewatering is provided in Appendix M, *Construction Considerations*.

Timing Considerations

Timing is an important factor in the installation of manufactured retention systems. Installation is generally a labor- and time-intensive process requiring favorable weather conditions. Because some of these methods are installed below the water line and may require excavation and turbidity control, dewatering will be required. Manufactured retention systems are best constructed during low-flow conditions, when dewatering is possible and when resident and anadromous fish are less likely to be impacted by construction activities. In order to install materials to the depth of scour, excavation within the channel bed will be necessary, which will also require temporary dewatering. Dewatering allows for ease of installation and prevents siltation of the stream during construction. This can be accomplished with a coffer dam during low-flow conditions.

Critical periods in salmonid life cycles, such as spawning or migration, should be avoided. In-stream work windows vary among fish species and streams. Contact the Washington Department of Fish and Wildlife's Area Habitat Biologist for information on work windows (see Appendix B, *Washington Department of Fish and Wildlife Contact Information*). Further discussion of construction timing and dewatering can be found in Appendix M.

In addition, planting success can be highly dependent upon the time of the year that the seed, cuttings or rooted-plant stock is installed. For this reason, installation of cuttings or rooted plants may need to be delayed until the most favorable planting season.

Cost

The cost of these techniques and systems is highly variable and depends upon the materials selected, bank height, dewatering methods selected and site-specific construction factors. Artificial streambank-protection systems, however, are usually selected over other techniques when the cost of more traditional techniques and materials are too high (due to availability or accessibility limitations), or when site limitations dictate alternative methods and materials. Furthermore, manufactured retention systems normally require considerably greater labor to install. As such, the cost of these techniques is typically much greater than more traditional techniques and often exceeds $100 per foot of bank protected.

For further discussion of construction costs, refer to Appendix L, *Cost of Techniques*.

MAINTENANCE

Maintenance requirements of manufactured systems depend upon the type of materials selected and the form of protection they provide. Monitoring will reveal maintenance needs, which may include repair or replacement of materials members or retention systems. As many of these systems have integrated members, loss or movement of a single unit may substantially jeopardize integrity of other units or members.

MONITORING

Monitoring Manufactured retention systems should involve survey and visual inspection, including periodic photo documentation. Monitoring should include detailed as-built surveying and photo documentation of the project area and upstream and downstream reaches to allow for evaluation of performance relative to design. Details on development of a monitoring plan are discussed in Appendix J, *Monitoring*.

Monitoring activities should focus on potential weak points in the design, such as transitions between treated banks and undisturbed upstream and downstream banks. Surveying should measure displacement of materials, particularly those connected to other materials. Monitoring frequency should be annual for a minimum of five years, or the anticipated design life of the structure, and conducted during low flows, when visual inspection of the toe of the bank is possible. Additionally, monitoring should be conducted following any events that equal or exceed the one-year flow during the first three years following construction. For further discussion of monitoring methods, refer to Appendix J.

For a comprehensive review of habitat-monitoring protocols, refer to Johnson, et al.[2] Habitat-monitoring protocols will likely require a monitoring schedule that is more comprehensive than that required for the integrity of the structure.

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a. Manufactured Retention System. Salmon Creek, Tributary to Columbia River. 2002.

b. Temporary Manufactured Retention System using fabric mat. Salmon Creek, Tributary to the Columbia River. Source: Clark County Public Utilities.

Figure 6-30. Applications of manufactured retention systems.

Woody Plantings
Biotechnical Techniques

DESCRIPTION

The placement of woody plantings is a bank-stabilization technique that relies on installed trees and shrubs to stabilize eroding banks, provide habitat benefits and improve aesthetics. The most commonly used type of woody plantings are live cuttings, especially those from willows, because of their ability to root well from locally collected, dormant cuttings and to colonize bare, alluvial deposits. Other woody plant materials, including containerized plants, bare-root stock and salvaged plants, are also commonly used. Ball-and-burlap materials are of limited use on streambanks; but, if budget allows, they can be useful on less frequently flooded upper floodplains. *Figure 6-31* shows various applications of woody plantings (at the end of this technique discussion).

This technique makes use of strong, relatively deep roots (up to several feet) that provide excellent soil-reinforcement capabilities, especially when plants are mature. Above-ground shoots and stems also help prevent surface erosion, encourage deposition and provide over-hanging vegetation cover along streambanks. The varied heights of vegetation within a mixed-species riparian zone provides a variety of wildlife habitat in terms of cover and food sources and ultimately will provide large, woody material for recruitment.

Woody plantings are also referred to as pole plantings, willow plantings, tree plantings, shrub plantings and riparian revegetation.

APPLICATION

Woody plantings can be effectively applied on a reach of degraded streambank characterized by toe erosion, marginal vegetative cover, and a relatively wide and shallow channel cross section. A woody-planting treatment may involve minor regrading or bank reshaping, but the bulk of the work is accomplished by planting suitable, native, woody species on the streambanks. With the proper techniques, woody plantings can be applied to banks with 2:1 slopes or shallower.[1,2]

Woody plantings are also a suitable treatment for controlling meander migration within a migration zone and at the edge of a migration zone, as long as toe erosion is the mechanism of failure. Aggrading reaches are also good candidates for woody plantings because of the colonizing ability of willows and other desirable, native riparian trees and shrubs. Woody plantings, especially in the case of low-growing willows, form dense stands of vegetation that reduce local velocities and offer root reinforcement, so they can also be used on floodplains to reduce the potential for channel avulsion (see the mechanism-of-failure discussion in Chapter 2, *Site Assessment*).

Although limited data are available on the erosion resistance of woody plantings, H. M. Sheicthl and R. Stern report that dense willow plantings (three to four years after planting) can provide erosion protection equivalent to that provided by riprap comprised of "large quarry stone."[3] While such data need to be viewed cautiously, they do suggest the potential of woody plantings as successful erosion-control mechanisms.

Refer to Chapter 2 and Chapter 3, *Reach Assessment* for further discussion of site and reach limitations and to Chapter 5, *Identify and Select Solutions* for information about how to select the most suitable bank-protection techniques.

As a stand-alone method of bank protection, woody plantings can provide excellent long-term benefits, on a streambank that has a relatively stable toe but has poor vegetative cover and possibly some surficial erosion or modest reach-based aggradation. Unless they are integrated with toe protection such as rock, log or coir-log toes, woody plantings are not appropriate where toe erosion is occurring. However, if used in combination with other bank-protection and erosion-control techniques, such as toe protection, herbaceous plantings and/or erosion-control fabric, woody plantings can provide immediate protection against surface erosion and toe scour.

Woody plantings are generally not the best choice of treatment in systems that are degrading because vegetation cannot control channel incision or downcutting (see Chapter 3).

Variations

Woody plantings include a wide variety of tree and shrub species, plant-material types, plant-material sizes and planting configurations. The length, diameter and age of live cuttings used in woody-planting bank treatment may vary extensively. Rows of cuttings may be oriented parallel or perpendicular to stream flow, placed horizontally or vertically, planted in clumps or on linear planting grids, and planted at shallow or deep depths.

Woody plantings may be used in conjunction with toe-stabilization techniques such as a roughened-rock toe or coir-log. Riparian shrubs and trees can also be incorporated into riprap, fabric-covered slopes and other forms of bank protection, and they are a major component of bioengineered techniques such as soil reinforcement. Several traditional types of bioengineered bank protection that are common variations of live cuttings are briefly described below. For a more thorough discussion of these and other bioengineering techniques, refer to the following texts: Biotechnical Slope Protection and Erosion Control;[4] Guidelines for Bank Stabilization Projects in the Riverine Environments of King County;[5] Water Bioengineering Techniques for Watercourse, Bank and Shoreline Protection;[3] and Streambank and Shoreline Protection, NRCS Engineering Field Manual.[2]

Live Stakes. Live staking, also called sprigging or willow staking, involves the insertion and tamping of live, unrooted vegetative cuttings into the ground.[2] Live stakes are a quick, inexpensive and effective means of securing a vegetative cover for control of soil erosion and shallow.[4] They can also be used to stake down and enhance the performance of erosion-control fabric and other soil-bioengineering techniques (e.g., fascines or brush mattresses) or to stabilize bare sections of slope between other soil-bioengineering techniques.[2] A system of stakes creates a living root mat that stabilizes the soil by reinforcing and binding soil particles together and by extracting excess soil moisture.[2] Note that, when live stakes are used alone, these desired effects do not commence until after vegetation establishment (at least one growing season).[3] Live stakes can be interplanted with rooted stock.

Cuttings used for live-stake applications should be unbranched, one- to several-year-old shoots of shrub and tree species.[6] Willow and cottonwood species are most commonly used, but other species may be suitable.[7] Cuttings for live stakes must be from a species with large, sturdy stems that can root readily and easily in a field setting. One- to two-inch-diameter cuttings are recommended,[5] but cuttings as small as 1/2 inch diameter may be used if cutting stock is sturdy enough to be pushed or driven into the soil without damage. Species with long, straight stems are much easier to cut and drive than those with crooked stems.[4] Recommended cutting length varies with site conditions. Cuttings two to three feet in length are commonly used at sites where the soil is moist. Longer cuttings are required at sites where the soil is dry in order to reach deep water tables. Longer cuttings may also be preferable when live stakes are being used to secure another bioengineering treatment to the bank. Side branches should be cleanly removed and the basal ends of cuttings should be pointed to facilitate driving them into the ground.

Live stakes can be pushed into the bank by hand or driven into the bank with a dead-blow hammer (i.e., a hammer with the head filled with shot or sand). In dense soil, it may be necessary to prepare pilot planting holes with a metal rod (such as rebar), auger or other specialized device, some of which are described in this section under *Construction Considerations*. The diameter of the pilot hole should be slightly smaller than the cutting to ensure a snug fit between the cutting and the soil. Cuttings should be placed in a random pattern at a density of two to five cuttings per square yard.[2,3,5] It is recommended that cuttings protrude above ground a maximum of one-fifth to one-fourth of their length to minimize water loss due to transpiration and to lessen the problem of root breakage caused by relative movement between the cutting and the ground.[2,3,4] Refer to Appendix H, *Planting Considerations and Erosion-Control Fabrics* for additional information.

"Joint planting" is the term commonly used when live stakes are driven into joints or openings in rock revetments. The vegetation works in conjunction with rock to provide benefits to the bank and stream offered by both forms of bank treatment. Root systems provided by live stakes bind or reinforce the soil and prevent washout of fines between and below the rock.[4] They also improve drainage on the slope by removing soil moisture. Above-ground portions of the plants offer shade and cover and dissipate some of the energy along the streambank. However, the addition of vegetation to the riprap matrix does not mitigate for all the negative impacts that the use of rock imparts to the stream.

Cuttings used in joint-planting treatments often need to be longer than those planted in unarmored banks; the minimum length depends on the thickness of the riprap. The basal ends of cuttings must extend into the backfill or undisturbed soil behind the riprap. Burying 4/5 of the length of the stake is optimal;[5] no less than 1/2 of the length is recommended. To prevent desiccation, it is important not to have a long length of stake exposed. Joint planting is more labor-intensive than ordinary live staking; and plant survival may be less than other planting techniques, especially in thick, riprap-revetment applications. Tools such as the *stinger* (described in this technique discussion under *Construction Considerations*) can make planting in riprap easier.

Cutting survival may be low in thick riprap unless soil is incorporated into the riprap matrix. Prior to cutting installation, dirty, pit-run gravel or soil with substantial clay content can be machine-placed over rock and pressed into the rock with a backhoe or excavator bucket. Clay soil is less likely to scour during high flows and holds moisture better than a sandy or silty soil. Following cutting installation (but prior to placement of seed or mulch), a tanker truck with a hose can be used to wash soil into the crevices and voids of the riprap to ensure good soil-to-cutting contact. Some engineers have expressed concern that inclusion of soil in riprap or the loss of vegetation that has been incorporated in riprap can reduce the structural integrity of the riprap. Engineers in British Columbia addressed this concern on the banks of the Frasier River by creating designated planting areas within the revetment. These planting areas consist of rebar frames in the shape of long tubes approximately 18 inches in diameter that extend from the riprap surface into the underlying soil. Each tube was lined with filter fabric and filled with soil suitable for plant growth. Cuttings were then planted inside each tube, with their basal ends extending deep into the underlying soil.

Brush Layering. This technique, also known as "branch packing," consists of dense rows of live cuttings, branches and/or rooted stock between layers of compacted soil. Individual layers are generally aligned horizontally or along the contour of the slope. Cuttings extend back into the bank and protrude slightly from the soil surface. As such, they immediately provide shallow soil reinforcement and protection from surface erosion, and they rapidly establish a vegetated streambank.[2, 3, 5] Bank stabilization is achieved by breaking up the bank into a series of smaller, vegetated slopes that dissipate energy, physically bind the soil within the root zone and promote the entrapment of sediment and debris. As cuttings are deeply covered in soil, there is little chance of them being uprooted during flood flows.[3]

Brush layers are particularly applicable in bank-protection projects that require fill. They are less commonly used on eroded slopes where excavation is required to install the cuttings. Brush layers can be used as a rehabilitation measure for seriously eroded and barren slopes and where patches of streambank have been scoured out or have slumped leaving a void. However, they are typically not effective in slump areas greater than four feet deep or four feet high. They are most effective once the stress causing the slump has been reduced or eliminated.[2]

Individual brush layers should be four to six inches thick and be comprised of rooted stock, branches, or cuttings 1/2 to two inches in diameter, and three feet minimum in length. Cuttings should be 20- to 25-percent longer than the depth of the terrace onto which they are placed. Place them in a random, crisscross pattern (not parallel to each other) to maximize their contact with soil and, thus, their rooting capability.[4] Recommended planting density varies from two[4] to six[3] branches per linear foot. As long as there is a sufficient percentage of live cuttings capable of propagation spread uniformly throughout the treatment, dead branches may be incorporated into the brush layers.[3] Recommended vertical spacing between brush layers ranges from three to eight feet, depending upon the erosion potential of the slope (i.e., soil type, rainfall, stream velocities, and length and slope of the bank).[4] A minimum spacing of one foot is recommended on fill slopes.[5] On long slopes, spacing should be closer at the bottom and increase as one moves up the slope. Fill used between layers of branches must be able to support plant growth. Individual layers are typically angled back into the slope at a minimum, 10-degree angle from horizontal. On drier sites, especially those requiring fill, this angle of inclination can be increased, and longer cuttings can be used in order for cuttings to reach deep water tables.

This method requires a relatively large number of live branches compared to live staking. However, on slopes subject to surface erosion, it offers an advantage over live stakes by providing immediate, shallow soil reinforcement and surface-erosion control. If plant material is inexpensive and abundant, the additional cost of brush layering over live staking will be minimal.

If the layers of soil are wrapped with erosion-control fabric, brush layering works in a fashion similar to the soil-reinforcement technique (see the discussion on this technique in this chapter). The addition of fabric to this technique adds relatively little to the cost, but greatly improves the erosional resistance, especially during the plant-establishment period.

Fascines. Also called wattles or contour wattles, fascines are long bundles of live cuttings that are bound together and secured to the streambank or floodplain with live and dead stakes. They are placed on the bank in one or more rows of shallow trenches that typically run parallel to the stream. Fascines work well to stabilize shallow gully sites and areas of general scour where the banks can be sloped back to 1:1 or flatter.[4] Fascines can serve to facilitate drainage on wet slopes if installed at a slight angle.[2] They work particularly well in straight reaches and on the inside bends of streams where erosion forces are low. Fascines help protect banks from shallow slides (one to two feet deep) and offer immediate protection from surface erosion. Bank stabilization is achieved by breaking up the bank into a series of smaller, vegetated slopes that dissipate energy, physically bind the soil within the root zone and promote the entrapment of sediment and debris. Installing erosion-control fabric between fascines can enhance the initial erosion-control capabilities of the system.

Plant materials for fascines should be 1/2 to two inches in diameter and at least three feet in length (the longer the better). The completed fascine should be eight to 10 inches in diameter and tapered at each end. For ease of handling, bundle length typically varies from 10 to 30 feet. The recommended spacing between fascines varies with the slope and erosion resistance of the soil. Fascines are not recommended as a stand-alone treatment on banks steeper than a 3:1 slope that are comprised of fill or erosive soils.[2]

Because fascines are oriented parallel to the soil surface, they are unable to reach deep water tables. Consequently, mortality can be high in all but the most consistently moist streambank sites. This method also requires a relatively large amount of live plant material and a larger work force compared to live-stake treatments. However, it does offer the advantage of providing immediate surface-erosion control.

Brush Mattresses. This variation, also known as "brush matting," consists of a thick layer (mattress) of overlapping live cuttings or branches placed on the surface of a streambank and secured with a combination of twine, wire, and live and dead stakes. Individual cuttings are either oriented perpendicular to stream flow so that their basal ends lie down slope,[2,3,5] or they are placed in a shingle-like manner, with basal ends angled upstream.[4,5] The bottom edge of the mattress is often anchored with a fascine. Brush mattresses function as mulch to immediately protect the bank from surface erosion, and it rapidly establishes dense vegetation.[5] The added roughness they provide reduces local velocities and promotes the entrapment of sediment and debris during flooding conditions. These effects increase with the age of the system as the vegetation becomes established. If there is a shortage of cuttings capable of propagation, a combination of live and dead branches can be used instead.[3]

The recommended maximum slope of a bank for both material survival and ease of installation is 3:1.[2] Though the treatment has been successfully applied to slopes up to 1.5:1,[4,5] applications on slopes steeper than 3:1 are recommended only if necessary and on cohesive soils. Mattresses will collect sediment and may collapse if constructed on too steep a bank. Branch layers should range from four to 18 inches thick, with the thicker mattresses being applied to streams that are larger or carry higher quantities of ice and bed load.[4,5] Cuttings should be six to nine feet long and approximately one inch in diameter.[2,3,4] 5 to 15 branches or stems should be placed per linear foot of stream to make up the desired thickness. To facilitate rooting, it is essential that the branches be in contact with the soil. Branches should lie flat against the bank and be covered with thin layers of topsoil, leaving the top surface of the mattress and the fascine slightly exposed.

This technique is most appropriate in moist sites where shallow or surface placement of cuttings will not be too dry for vegetation establishment. The relatively large quantity of plant materials needed and the labor-intensive nature of the treatment make brush mattresses best suited to short segments of streambank and on sites where both inexpensive material and volunteer hand labor are abundant. They should not be used on slopes that are experiencing mass movement or other slope instability.[8]

Emergency

Woody plantings are not effective in emergency situations because of the time required for establishment and root colonization of streambank soils. In addition, installation of woody plant materials requires advance planning, and installation can be slow and labor-intensive.

EFFECTS

The effect of woody plantings as bank protection is limited in the first growing season, though it rapidly increases in subsequent years after roots and above-ground shoots and stems increase in size and coverage. On relatively undisturbed streambanks, woody plants provide stabilization to depths of two to three feet by physically binding soil particles and adding tensile strength to potential shear layers in the soil.[9] Above-ground shoots and stems may provide some protection against surface erosion, but usually less than continuous mats of herbaceous vegetation. Woody plantings add structural habitat diversity to banks and floodplains and can provide overhanging cover for fish, eventually contributing woody material to channels. Deposition of sediment may also be encouraged by the increase in hydraulic roughness created by dense stands of woody vegetation.

DESIGN

The following is a short summary of some design considerations for woody plantings. are the best option for your situation. Please refer to Appendix H for a more detailed description of the bulleted items below. Also, an understanding of fluvial and riparian processes will greatly improve the chances of success of any woody-plantings project. Conceptual design drawings are shown in *Figure 6-32*.

- Develop design criteria. Design criteria are detailed guidelines that will identify specific requirements related to plant performance, including acceptable plant-establishment period, size of plants, growth characteristics and species diversity.
- Conduct a site review of the project and reference sites. Identify existing plant species, their abundance and distribution, the lower limit of perennial vegetation, the depth to groundwater, the types of soil, the availability of light, hydrology and geographic characteristics, and land use. Choose an active reference site, preferably in the same or nearby watershed with similar site conditions to aid in the design of a planting plan for the project site.
- Identify site constraints. Site constraints are site-specific factors that may limit the success of the bank-treatment design. They include biological, physical, economic and construction-sequencing issues.
- Select plant materials for the project. This may include unrooted live cuttings, rooted cuttings, bare-root stock, containerized plants and, in some cases, ball-and-burlap stock. If you decide to seed the streambank, the seed should be placed under erosion-control fabric to reduce the chance of seeds washing away during flood flows (this is true of all seeding projects). The type of plant material selected depends upon the project scope, design criteria and the overall budget.
- Select plants. For each plant-material type, select plant species based on your design criteria, the species' compatibility with site conditions and their availability. Consult your reference site to identify plants with the highest likelihood of survival. Plant species native to the project area should be used, and using a broad variety of species will improve the likelihood of project success.
- Within each hydrology-based planting zone, determine planting density and layout for all plant materials and each species based on design criteria and cost.
- Determine site-preparation requirements, timing of installation and the proper planting techniques for all plant materials.
- Consider the need for maintenance such as irrigation, weed control and the control of animal browsing. Monitoring data will help determine maintenance activities needed to maintain healthy plant growth.

Site conditions that may inhibit woody-planting success are numerous. Consequently, the design and planning of revegetation efforts requires knowledge in horticulture or plant biology, with a specific emphasis on riparian ecology. Success is dependent on proper selection, handling, storage and installation of plant material. Poor success may result if, for example, soils are not compatible with selected vegetation, cuttings fail to reach the summer water table, beavers destroy installed plants or plants are not installed in the proper hydrologic zone. More details on revegetation considerations are discussed in Appendix H.

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BIOLOGICAL CONSIDERATIONS

Mitigation Requirements for the Technique

No mitigation is needed for this technique.

Mitigation Benefits Provided by the Technique

Woody plantings, if properly designed and implemented, can provide overhanging cover for fish, structural diversity for birds and wildlife, detritus for aquatic invertebrates and long-term recruitment of large, woody material. Consequently, this technique avoids impacts that may degrade habitat, and it can be used to compensate for habitat impacts created by other streambank treatment activities such as loss of riparian function, cover, complexity and flood refuge.

Please refer to Chapter 4, *Considerations for a Solution* and Matrix 3 in Chapter 5 for additional information on biological and mitigation considerations.

RISK

Habitat

Except for the time that may be required for woody plantings to establish and mature, properly designed woody plantings are excellent from a habitat perspective.

Infrastructure

Woody plantings are typically compatible with adjacent infrastructure only in cases where they are a component of more resilient bank-stabilization techniques, such as a rock toes, soil-reinforced banks or log cribwalls, which provide stable transitions into infrastructure.

Reliability/Uncertainty of Technique

Woody-planting success can vary significantly from site to site. In general, western Washington is a very hospitable climate in which to establish vegetation due to the long growing season and plentiful moisture. Establishing woody plants in eastern Washington can be much more challenging, requires more careful planning and generally needs more intensive maintenance.[10] Common causes of failure include incorrect planting locations, inability of plant material to reach the summer water table, damage by wildlife and livestock and inability of installed plants to compete with naturally establishing riparian vegetation.

CONSTRUCTION CONSIDERATIONS

Materials Required

Several types of materials may be beneficial to use during woody-plant installation, including general backfill, topsoil, compost and slow-release fertilizers. These are discussed in more detail in Appendix H.

The project's scope and site conditions will determine the types of tools required for the installation of woody plants. Where soils are fine-textured, moist and not over-compacted, woody plants can be effectively installed with hand tools. Often, however, it is more effective to use some type of mechanized planters to create planting holes, especially if long cuttings are being installed or if soil is coarse-textured and over-compacted. Conventional earthwork equipment, such as Bobcats, backhoes, augers, excavators and tree spades can be useful for woody plantings. Additionally, restoration practitioners have developed planting devices specifically for woody plantings. Some examples include the stinger, which is used for inter-planting riprap; the ripper, which is used to plant cemented floodplain soils; and the water-jet stinger,[1, 12] which uses pressurized water to create a deep hole for planting long willows in fine-textured soils. These tools are described briefly below.

Stinger Method

The stinger method makes it easier to plant cuttings in compacted streambank soils and riprap revetments. As an attachment to a backhoe or excavator, the stinger can push three- to four-inch-diameter cuttings into the soil to depths of up to approximately six feet.[2, 12] The Janicki stinger was developed in 1995 for the Washington Department of Fish and Wildlife to attach to the bucket of an excavator. It consists of a solid steel rod, approximately three to four inches in diameter, that creates a pilot hole through coarse or rocky layers of streambank or riprap and stops when it reaches the softer, native soil underneath (subsoil). The finer subsoil serves as a rooting zone for installed willow or cottonwood pole cuttings. Cuttings are inserted into the pilot holes by hand and pushed down to the required depth with the heel of the bucket. Care is required to ensure that cuttings are footed in moist subsoil and that there is a continuous tight fit between the cutting and the soil. The cutting should make its own hole through the native subsoil. No more than one-half of the cutting should protrude above the soil; six inches is recommended. This system has been used across western Washington with great success and eases planting in difficult conditions such as floodplains where water tables are as much as six feet beneath the ground surface or in streambanks with riprap layers up to five feet thick. The Janicki stinger can plant 40 to 50 cuttings per hour on average. Because the Janicki stinger can push the cuttings in only as far as the riprap surface, cutting survival may be low in thick layers of riprap, unless soil has been incorporated into the riprap matrix.

A planting device similar in purpose to the Janicki stinger is the "expandable stinger," which consists of a pair of eight-foot-long, elongated probes, with an internal plant receptacle. The bottom tips of the probes can be closed to hold the plant within the plant receptacle and opened to release the plant into the ground. Like the Janicki stinger, the expandable stinger also attaches to an excavator bucket. The cutting is placed inside the probe's plant receptacle, and the excavator drives the probe into the ground. Once the probe has reached the proper depth in the soil or riprap, the operator opens the probe (it operates hydraulically from the cab of the excavator), and the cutting is released. The probe is then removed from the hole; the probes are closed; a new cutting is inserted, and the process is repeated. The advantages of the expandable stinger over the Janicki stinger include:

- The cutting is protected at all times (leading to potentially higher survival rates) rather than being pounded into place.
- Smaller-diameter cuttings can be used. The probe can accommodate 1/2-inch- to four-inch-diameter cuttings that are up to four feet in length. Larger cuttings may be held in the tip of the probe and driven into the soil.
- The "shear wall," a compacted wall in the planting hole created when planting tools are inserted into the soil, is minimized or eliminated. The probe tip of the expandable stinger has longitudinal ribs that break up the compacted soil around the walls of the planting hole as the probe is removed and allows the now-loosened soil to fill the hole. Without this feature, shear walls can be created, hampering the proper dispersal of roots and often resulting in poor or unsuccessful growth.
- Field crews remain relatively safe on the top of the bank rather than having to climb along the banks in close proximity to heavy equipment operation.

The expandable stinger is capable of planting in streambanks, floodplains and through riprap up to four feet thick. It has been used to plant 30 to 250 cuttings per hour, depending upon site conditions.

A variation on the expandable stinger is capable of planting three-inch-diameter rooted-plant plugs into unarmored streambanks at a rate of up to three hundred per hour.

Ripper Method

The ripper was also developed to facilitate revegetation efforts in cemented floodplain soils with deep water tables. It consists of a five-foot-long shank pulled behind a D-8 Caterpillar bulldozer or equivalent. The shank creates a narrow trench in the soil. Up to four workers drop cuttings into the trench from a platform on the tool bar of the ripper as it moves along. The ground may collapse under its own weight back onto the cuttings. More often, however, to ensure good soil contact with the cuttings, the operator must ride over soil mounded up to one side of the trench with the outside of the bulldozer track. The minimum width between trenches is the width of the bulldozer track, approximately four to five feet. Trenches are normally placed perpendicular to the stream or at a downstream angle. Advantages of the ripper include that it loosens the soil around the cutting to promote good root development, and the trenches of relatively uncompacted material can help to draw water from the stream to recharge the aquifer. Disadvantages include that it can only be used on large-scale projects, and the ground is left in a roughened state that may not be acceptable if immediate aesthetics are of concern. The ripper has been used to plant an average of 1,000 cuttings (up to six inches in diameter) per hour into cemented floodplain soils.

Water Jet Stinger Method

Another method to create a deep, narrow hole for long willow or cottonwood pole cuttings is the water jet method.[1,11] Unlike the stinger, this method is designed for sites with fine-textured soils, a low rock or gravel content, and relatively deep water tables. This planting system consists of a gas-powered pump that forces water from the nearby stream through a long rod with a special nozzle. The nozzle creates a pressurized flow capable of creating a six-foot-deep hole in approximately 20 seconds (in good conditions). The length of rod depends on the length necessary to reach the summer water table, but typically ranges from three to 10 feet. If the willow cuttings are promptly placed in the scoured holes, the slurry of saturated sediments within the hole will form a tight fit between the cutting and the soil, which increases cutting survival.

Timing Considerations

The optimum time to plant depends on the specific type of woody plantings under consideration, the availability of water or the potential for irrigation, and project scheduling. Unrooted cuttings should be harvested and planted during the spring or during the fall dormant season. Bare-root plants should be planted during the late winter/early spring. Containerized plants and salvaged plants have a wider planting window. They can be installed almost any time of year, provided they will receive adequate water, but best results occur with spring or fall plantings. All work on the streambank should be timed to coincide with flows that are low enough for crews to reach planting zones.

Cost

Some approximate costs for installed woody plant material types are as follows:

- three-foot-long willow cutting–$2.00;
- six-inch-diameter willow post–$25.00;
- ten-cubic-inch shrub tubeling–$2.00;
- one-gallon containerized shrub–$8.00;
- locally salvaged willow clump–$25.00;
- two-foot-diameter, bare-root shrub–$1.00; and
- 1.5-inch caliper ball-and-burlap tree–$200.

More information on the cost of woody plantings and how to calculate the total number of plants required per acre is provided in Appendix L, *Cost of Techniques*. Costs for use of the stinger and water-jet method depend upon equipment costs, site conditions and the scale of the job.

MAINTENANCE

General maintenance needs for installed woody vegetation may include, but are not limited to irrigation, browse control (beaver, livestock, deer and small mammal), pruning, weed control and fertilization. Some of these topics are discussed in greater detail in Appendix H. Maintenance should be initiated based on predetermined success criteria and monitoring findings.

MONITORING

Woody-plant monitoring is critical to project success and should be linked to maintenance activities, such as irrigation, browse or beaver control and, if needed, replanting. Monitoring should be conducted monthly during the first full growing season after installation and can be reduced to a single, annual visit in subsequent years. In the first year after planting, it is easy to measure survival of all installed plants by a physical count; but, with increased density as vegetation fills in, it may be necessary to use cover rather than count of individual plantings as a measure of plant survival. Another consideration, specifically related to riparian zones, is that any survival monitoring criteria should anticipate that deposition of alluvial material on banks or floodplains may limit survival of installed plant material. However, these conditions are conducive to the natural establishment of other desirable riparian species. More information on monitoring is provided in Appendix J, *Monitoring*.

For a comprehensive review of habitat-monitoring protocols, refer to Johnson, et al.[13] Habitat-monitoring protocols will likely require a monitoring schedule that is more comprehensive than that required for the integrity of the structure.

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a. Live Stakes planted through Coir Fabric.
Source: Inter-Fluve, Inc.

c. Rows of Woody Plantings. Cedar River Levee.

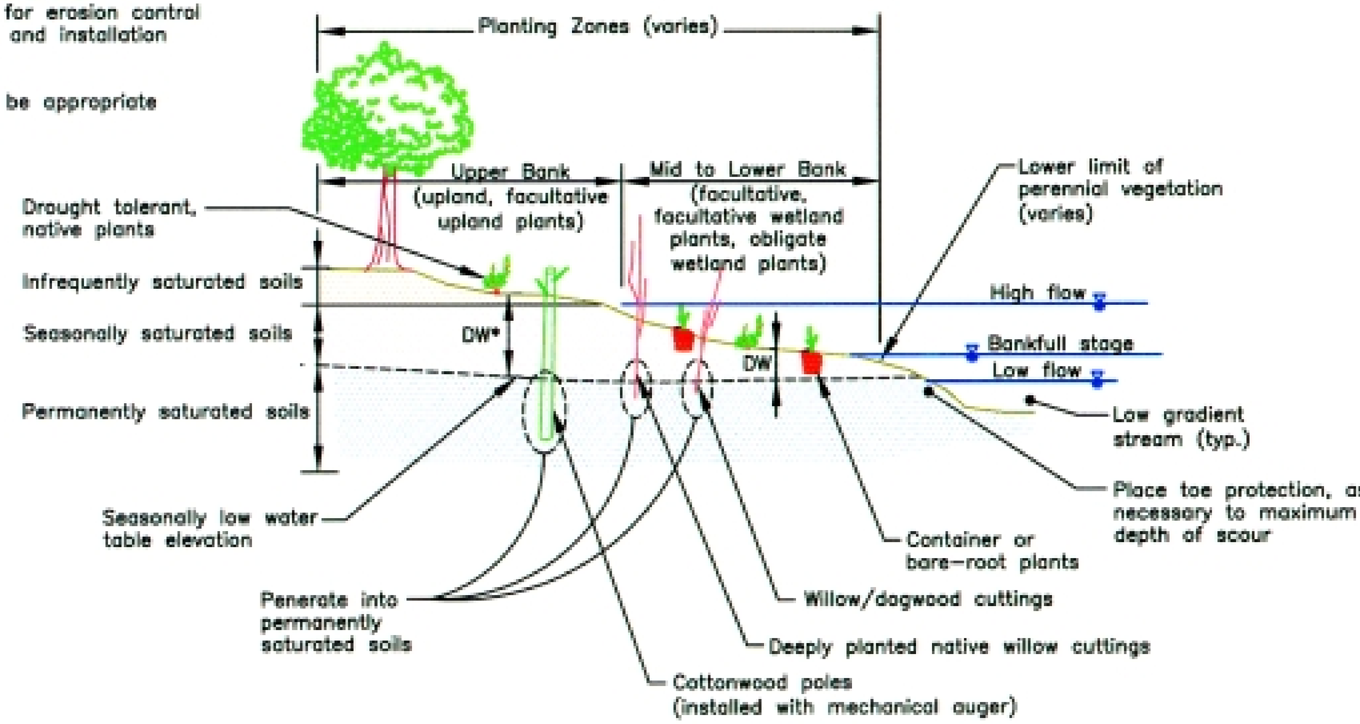
b. Woody plantings with tube protector to protect from being girdled by rodents. Tucannon River.

d. Woody Plantings with fencing to protect from animal browsing, especially beaver. Nooksack River.

Figure 6-31. Various applications of woody plantings.

Notes:

1. Planting zones provided are approximate. Appropriate plant species and distribution vary with each individual site and plant species characteristics. See Appendix H for additional planting guidelines.
2. Use of erosion control fabric is site dependent. See Appendix H for erosion control fabric application, selection, and installation guidelines
3. Herbaceous plantings might be appropriate with woody plantings



HYDROLOGY-BASED PLANTING ZONES AND
TYPICAL WOODY PLANTING BANK TREATMENT

* Depth to low water table (varies)

SECTION VIEW

NOT TO SCALE

FIGURE 6-32	WOODY PLANTINGS CONCEPTUAL DESIGN	INTEGRATED STREAMBANK PROTECTION GUIDELINES www.wa.gov/wdfw/hab/salguide/strmbank.htm

Herbaceous Cover

Biotechnical Techniques

DESCRIPTION

Herbaceous cover is a bank-stabilization technique that consists of planted or installed herbaceous vegetation. This technique is used to improve bank stability, fish and wildlife habitat, and site aesthetics. Herbaceous vegetation consists of grass and grass-like wetland plants and includes rushes, sedges, ferns, legumes, forbes and wildflowers. In contrast to woody vegetation, herbaceous vegetation tends to have roots that are shallow, fine and dense. Above-ground shoots tend to form a more continuous mat across the soil surface than typically observed in woody plants. *Figure 6-33* (at the end of this technique discussion) shows various applications of herbaceous cover.

Herbaceous vegetation is usually planted as seed, but other widely used riparian herbaceous planting materials include containerized plugs, bare-root seedlings, rhizomes and tubers. Herbaceous plantings might also be referred to as seeding, groundcover, sprigging, plugging, hydromulching, drill seeding or broadcast seeding. Refer to Appendix H, *Planting Considerations and Erosion-Control Fabrics* for a more detailed description of different planting material types.

APPLICATION

Herbaceous cover is an upper-bank treatment. It can be used as a stand-alone treatment or in conjunction with other treatments.

A typical application of herbaceous cover as a stand-alone treatment is on a streambank that has a relatively stable toe but has poor vegetative cover and possibly some surficial erosion or modest, reach-based aggradation. Herbaceous cover may also be an excellent choice as ground cover in parks and urban areas where flood conveyance and ease of maintenance is important. For example, on low-gradient streams where uniform coverage of the floodplain surface can be ensured, herbaceous cover may be used to protect an otherwise bare soil surface from stream channel avulsions. As summarized in Matrices 1 and 2 in Chapter 5, *Identify and Select Solutions*, under no circumstances should herbaceous cover be used as the primary method to control major bank-erosion problems, but this approach can provide an important component of a composite solution.

Herbaceous cover is not an appropriate stand-alone bank treatment for sites where undercutting or mass failure occurs because it does not address the mechanism of failure (see Chapter 2, *Site Assessment* and Matrices 1 and 2 in Chapter 5). Only when used in combination with toe protection and erosion-control fabric is herbaceous cover an acceptable treatment for banks affected by local scour. Due to the relatively shallow rooting depths of grasses and grass-like plants, this treatment should not be used on reaches where degradation and channel downcutting is widespread. The only exception to this limitation is erosion caused by an extreme event that is not likely to occur again in the near future and when damage from such an event is expected to be limited.

Variations

Variations of this treatment include the use of erosion-control fabric and different plant types. Erosion-control fabric should be used with seeding placement unless the risk of seed washing away is minimal. Erosion-control fabric is seldom required for the protection of rooted stock because plants are physically attached to the soil surface. An excellent, low-cost type of herbaceous cover, frequently used in streambank reconstruction projects, is sod salvaged from the project site and placed over subsoil. The dense root/soil mass of a sod mat is relatively resistant to washing away during flood flows and the well-developed root masses have the potential to quickly establish with minimal maintenance. Another interesting type of herbaceous plant material is a prevegetated coconut mat that resembles conventional turf sod. Available from some Washington native-plant nurseries, these products can be an effective, low-risk (but expensive) means to quickly establish herbaceous cover.

Emergency

Herbaceous cover is not appropriate for emergency situations, due to the length of time required for establishment of a dense stand of vegetation.

EFFECTS

Herbaceous cover is effective once vegetation matures and establishes uniform coverage of the soil surface. Roots, especially of highly desirable streambank species such as sedges or rushes, physically bind soil particles together in a cohesive unit. Meanwhile, above-ground shoots and stems form a continuous soil cover that reduces velocities and erosional forces at the soil/water interface. Due to maximum rooting depths of one to two feet, herbaceous cover can provide excellent erosion resistance on small streams where streambanks are less than two feet in height. On taller streambanks, herbaceous plants are best used in combination with other bank-protection treatments because their roots may be too shallow to resist the long-term hydraulic forces of flowing water on their own. Dense, herbaceous cover can also provide good weed control and aesthetic benefit.

DESIGN

Design of an herbaceous-cover treatment must consider site conditions and specific planting issues as summarized below. Conceptual design drawings are shown in *Figure 6-34*. The following list of sequential steps provides general design guidance given the number of plant types that may be used and variability from site to site (see Appendix H for more information on these items):

- Develop design criteria. Design criteria are detailed guidelines that identify specific treatment requirements related to acceptable plant-establishment periods, desired size of plants and species diversity.
- Conduct a site review of the project and reference site. Choose a functional reference site with similar soil, light and moisture characteristics, preferably in the same or nearby watershed with similar site conditions, to aid in the design of a planting plan for the project site. Identify existing plant species, abundance, distribution and the lower limit of perennial vegetation. These characteristics can be replicated from the reference site to the project site.

- Identify site constraints. Site constraints are factors specific to the proposed site that could limit the success of the bank-treatment design. They include biological, physical, economic and construction-sequencing issues that may affect the timing of plant installation.
- Select herbaceous plant types for the project. The type of plant(s) selected depends upon the project scope, design criteria and overall budget.
- Select plant species. Select plant species based on design criteria, compatibility with site conditions and availability. Consult the reference site to identify plants with the highest likelihood of survival. In most cases, native species should be used. A diversity of species is encouraged to improve the likelihood of project success.
- Determine planting density (including seed rate) and layout within each hydrology-based planting zone for all plants based on design and cost criteria.
- Determine site-preparation requirements, timing of installation and the most appropriate planting techniques for all plants.
- Consider the need for maintenance, such as mowing, irrigation and weed control. Monitoring data will help determine maintenance requirements.

For additional information on developing seed mixes, see Appendix H and the *Soil Rehabilitation Guidebook*.[1]

Erosion Resistance

A limited amount of literature is available on the erosion resistance of mature, herbaceous cover and is based, in part, on research generated from studies on grass-lined channels in dam spillways. These findings are incorporated into HEC-15 (1988),[2] a standard hydraulic engineering reference, but should be used cautiously. Depending upon the soil type, grass species and condition of the stand of grass, the erosional resistance of mature stands of tested grasses ranges from 0.4 to 3.3 lbs. per square foot (comparable to a range of approximately one- to six-inch diameter gravel/rock bank protection).

Along most streambanks, installation of seed is done in conjunction with erosion-control fabric to reduce the risk of seed washing away during flood events. This is especially important along the lower banks and outside bends of streams. In some cases (e.g., along inside bends, upper banks and low-gradient creeks), seed may be less prone to washout during flood flows, but a decision not to use erosion-control fabric on seeded streambanks should be made by an experienced stream specialist. Rooted, herbaceous plants, compared to seed, are less likely to be washed away by flood flows and are a better choice as a stand-alone technique in erosive sites.

BIOLOGICAL CONSIDERATIONS

Mitigation Requirements for the Technique

No mitigation is required for this technique. For additional information on mitigation considerations, refer to Chapter 4, *Considerations for a Solution* and Matrix 3 in Chapter 5.

Mitigation Benefits Provided by the Technique

Herbaceous cover can provide mitigation value for riparian and aquatic habitat loss. As mitigation, herbaceous cover can provide near-bank cover (especially when grasses are tall), detritus for aquatic invertebrates and structural diversity for birds and wildlife. As a result, this technique avoids impacts that may degrade habitat and can be used to compensate for habitat impacts such as loss of riparian function, cover, complexity and flood refuge. Chapter 4 and Matrix 3 in Chapter 5 provide additional information on biological and mitigation considerations for herbaceous cover.

RISK

Habitat

No risk to habitat is caused by this treatment.

Infrastructure

This technique is not appropriate for bank protection where infrastructure is at risk, unless it is part of a well-designed biotechnical treatment.

Reliability/Uncertainty of Technique

In western Washington, the climate and associated growing season make herbaceous cover much easier to successfully implement than in other parts of the state. In those parts of the state where drought, poor soils and shorter growing seasons occur, irrigation may be necessary for successful propagation of a herbaceous cover. Troubles with seeding can often be linked to poor soil-to-seed contact (insufficient compaction), over-compaction, improper timing and/or drought. Rooted, herbaceous plants may fail if the hydrologic regime is inappropriate, or if planting conditions and associated soil moisture are inadequate during the critical establishment phase.

CONSTRUCTION CONSIDERATIONS

Materials Required

Materials required to implement herbaceous cover along a streambank include the specified plants and, if required, imported or salvaged topsoil, soil amendments and erosion-control fabric. Surficial mulches are not used along streambanks because they are subject to being washed out during high flows. Similarly, conventional chemical fertilizers are not recommended as they can contribute excessive nutrients to the adjacent waterway.

The equipment necessary to install herbaceous cover depends upon the scale of the project. For example, on relatively small jobs, landscaping equipment may be sufficient to scarify compacted soils or incorporate soil amendments and topsoil into the rooting zone. But on large jobs, a variety of farm equipment and heavy earthwork machinery may be more cost effective. Application of seed also depends upon site conditions and the scale of work and can range from mechanical hand seeders on narrow, hard-to-reach streambanks to mechanized drill seeders or hydromulching equipment on more accessible adjacent floodplains. Light compaction of seeded areas, which is recommended after seed application, may be undertaken with excavator buckets, excavator tracks and/or conventional vibrating or roller compactors. Hand tools are generally the best equipment to use for installing most rooted forms of herbaceous cover.

Timing Considerations

The timing for planting herbaceous cover along streambanks must be based on a number of site and regional factors, including seasonal moisture and temperature patterns, timing of flood flows, and the timing of any streambank-construction activities. Since there is a wide range of climates in Washington, timing of plantings will need to be tailored to the specific site. Nonetheless, as a very general guideline, spring and fall are good times to install most herbaceous plants, but mid-summer and early fall should be avoided unless supplemental irrigation is provided. For further discussion of timing considerations, refer to Appendix M, *Construction Considerations*.

Cost

The cost to revegetated a streambank with herbaceous cover alone may range from $1 to $3 per foot of bank. Costs can range up $6 per foot if topsoil and erosion-control fabric are required. An approximate cost for native seed is $10 per pound but varies by species and the volume ordered. Costs to hand broadcast seed along a bank-stabilization project are approximately $750 per acre. Hydroseeding costs depend upon acreage, but can range from $1,000 to $2,000 per acre. Installed, 10-cubic-inch, containerized herbaceous plugs are about $1 to $4 each. Native, bare-root herbaceous plants (typically wetland species) can be purchased and installed for about $1 to $2 each. Refer to Appendix L, *Cost of Techniques* for additional information on cost and to Appendix H for conversion of planting densities to total number of plants required per acre.

MAINTENANCE

Herbaceous cover requires little maintenance, if any, and is relatively self-sustaining once established. In some cases, irrigation and weed control may be required and should be undertaken if monitoring indicates a need. During the establishment phase, it is also important to limit foot traffic and livestock access. Livestock access following the establishment phase should be limited and carefully monitored to prevent damage to vegetation and soils.

MONITORING

Monitoring herbaceous cover should include success criteria established as part of the design process and the identification of indicators for initiating maintenance activities (if needed). Monitoring should consist of inspecting for any signs of erosion, including surficial and toe of bank erosion, and for loss of soil or damage to erosion-control fabric. Important monitoring parameters include uniformity of coverage and weed coverage. Uniformity of coverage and the presence of weeds can be determined through casual visual survey, or by establishing specific criteria for measuring coverage and weed density. Full, herbaceous cover can generally be accomplished during the first growing season with minimal weed competition. Even so, survival criteria should anticipate the deposition of alluvial material on planted banks and floodplains that may limit the survival of installed cover but may also create conditions conducive to the natural establishment of other desirable riparian species. Consequently, success criteria should address maintenance activities associated with deposition of fine materials.

Monitoring should be conducted monthly during the first full growing season after installation (and perhaps linked to flood events) and can be reduced to a single, annual visit in subsequent years. For further discussion of monitoring methods, refer to Appendix J, *Monitoring*. For a comprehensive review of habitat-monitoring protocols, refer to Johnson, et al.[3] Habitat-monitoring protocols will likely require a monitoring schedule that is more comprehensive than that required for the integrity of the structure.

REFERENCES

1 Soil Rehabilitation Guidebook. 1997. Forestry Practices Control Guide for British Columbia. Appendix 2: Grass and Legume Seeding.

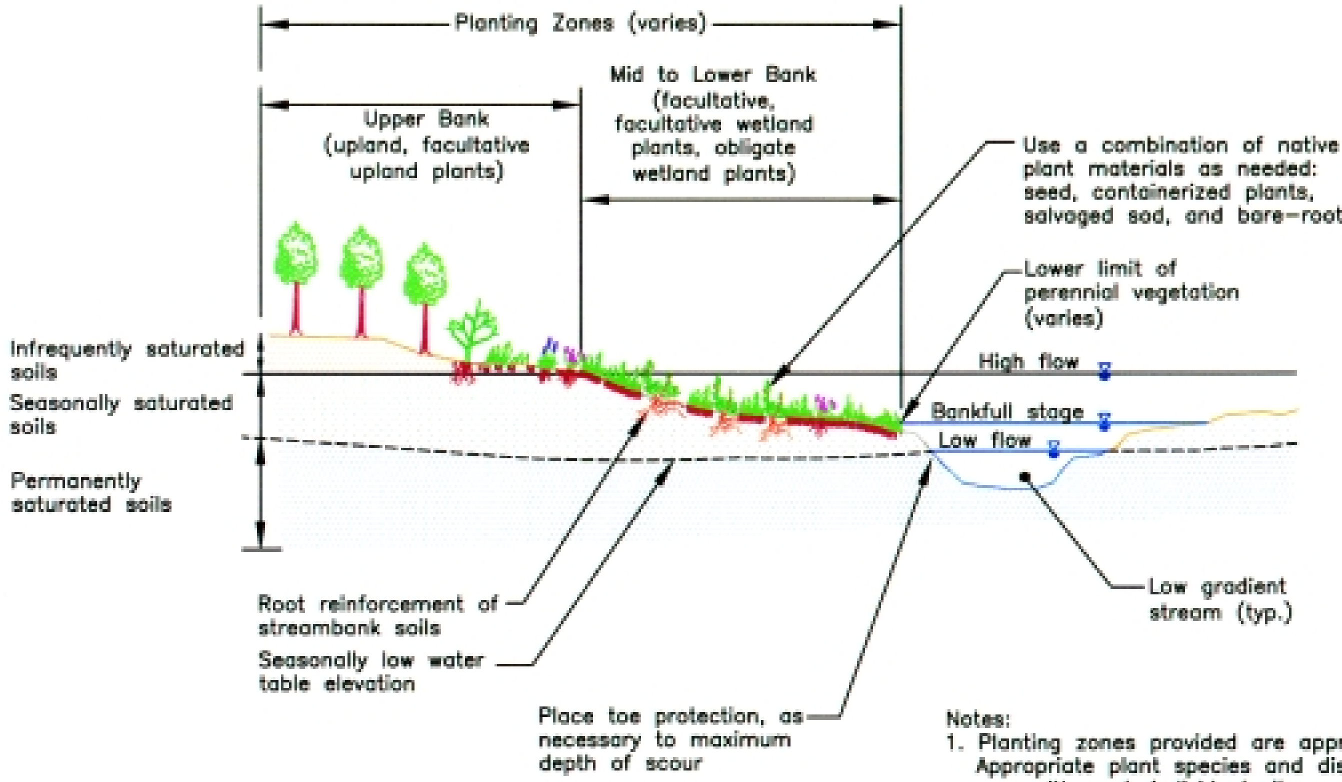
2 U. S. Department of Transportation, Federal Highway Administration. 1988. Design of roadside channels with flexible linings. Hydraulic Engineering Circular No. 15. Publication No. FHWA-IP-87-7.

3 Johnson, D. H., N. Pittman, E. Wilder, J. A. Silver, R. W. Plotnikoff, B. C. Mason, K. K. Jones, P. Roger, T. A. O'Neil and C. Barrett. 2001. Inventory and Monitoring of Salmon Habitat in the Pacific Northwest - Directory and Synthesis of Protocols for Management/Research and Volunteers in Washington, Oregon, Idaho, Montana, and British Columbia. Washington Department of Fish and Wildlife, Olympia, WA.

a. Wind River.

b. Sauk River.

Figure 6-33. Applications of herbaceous cover.



Notes:

1. Planting zones provided are approximate. Appropriate plant species and distribution vary with each individual site and plant species characteristics. See Appendix H for additional planting guidelines.

2. Use of erosion control fabric is site dependent. See ISPG Appendix for erosion control fabric application, selection, and installation guidelines.

3. Woody plantings might be appropriate with herbaceous plantings, especially on upper bank.

NOT TO SCALE

FIGURE 6–34	HERBACEOUS COVER CONCEPTUAL DESIGN	INTEGRATED STREAMBANK PROTECTION GUIDELINES www.wa.gov/wdfw/hab/ahg/strmbank.htm

DESCRIPTION

Soil reinforcement refers to a system of soil layers or lifts encapsulated or otherwise reinforced with a combination of natural or synthetic materials and vegetation. Most often, the lifts are oriented along the face of a bank in a series of stepped terraces. When used with degradable fabrics, the fabric will provide one- to four-year erosion protection, giving installed vegetation the time it needs to become well established for long-term bank stabilization. In situations where increased fabric strength and longevity are needed, synthetic fabrics can be used to provide both short- and long-term structural integrity. Nearly all applications of this approach are integrated with toe protection below the lower limit of vegetation. *Figure 6-35* (at the end of this technique discussion) shows various applications of soil reinforcement throughout Washington State.

These systems are also known as fabric-encapsulated soil, fabric-wrapped soil, soil burritos, vegetated geogrids or soil pillows. This technique is included in the biotechnical section of these guidelines, but it could also be considered a structural measure when designed with geotechnical components. Soil reinforcement is included among biotechnical measures because of the short lifespan of some fabric components and the importance of long-term vegetative reinforcement.

APPLICATION

Soil reinforcement is a frequently used approach to stabilizing or reconstructing eroding banks on small creeks and large rivers where a resilient and proven bioengineered or biotechnical treatment is needed. It is suitable for use where a wide range of bank-failure mechanisms occur, including toe erosion, mass wasting and scour. (See Chapter 2, *Site Assessment* and Chapter 3, *Reach Assessment* for information on the mechanism and causes of bank failure). The stepped configuration of a series of lifts lends itself to a variety of slopes ranging from 1:1 to flatter than 3:1 making them useful where slopes cannot be cut back. If used in a series of terraces, lifts can be fit to bank heights of a few feet to more than 30 feet.[1]

A structural toe technique (see *Roughened-Rock Toes* and *Log Toes* techniques in this chapter) can be combined with a fabric-covered soil, providing a considerably higher level of protection against bank erosion than vegetation alone. When used in such combination, fabric-encapsulated soil lifts built with degradable fabrics can conservatively withstand bank tractive forces of one pound per square foot.[2] The use of synthetic fabrics can further increase shear-stress resistance to match the performance of many traditional rock methods. This type of system provides immediate protection from surface erosion and structural bank failure because soil is not exposed.

The screening matrices in Chapter 5, *Identify and Select Solutions* provide additional guidance on the applicability of soil reinforcement based on the mechanism of streambank failure and causes of streambank erosion.

This technique tends to form relatively uniform and smooth streambank edges that may not provide immediate roughness and cover that is desired from a fish habitat perspective. While it is expected that large roots of trees and shrubs would eventually colonize the soil lifts and create desired roughness and bank diversity, such benefits take many years to come to fruition. Consequently, unless incorporated with a roughened toe (with associated large woody debris), this technique is not recommended if a project requires immediate bank roughness for fish habitat.

While soil reinforcement is an acceptable treatment on aggrading reaches (see Chapter 3), the use of an associated structural toe may not be necessary. Along degrading reaches, reinforced soils are suitable in combination with grade-control structures.
A geotechnical evaluation may be required in over-steep, highly erosive project sites to ensure that slope configuration, fabric types and internal soil drainage are adequate to meet the need.

Variations

The soil-reinforcement technique can be applied using a variety of fabrics and structural components. Numerous types of woven, nonwoven, degradable and nondegradable fabrics can be used alone or in combination. Different fabrics provide varying levels of protection and longevity. Additionally, incorporation of geogrids and other geosynthetic materials within lifts can provide significant structural integrity to steep banks and areas of mass wasting. Soil reinforcement used in combination with gravel filters and drains create a workable solution where drawdown and other drainage problems are prevalent or where they are the mechanism of failure. Refer to the discussion in this chapter on *Subsurface Drainage Systems* for more detailed information about drains.

A number of configurations can also be used for the toe foundation. Natural Resources Conservation Service guidelines[3] specify that a fabric-wrapped toe can be created that resembles the upper lifts in appearance, but it incorporates coarse alluvial substrate. D. E. Miller describes a more traditional toe foundation made of unwrapped stone.[4] In addition, soil reinforcement is one of the few techniques that can function as a deformable bank. In areas of low risk, deformable-bank treatments allow restoration of the channel's natural migration to take place, regulated by bank vegetation, just as it is in natural settings. A deformable bank uses somewhat undersized toe material (may be mobile at two- or five-year recurrence flows) that is wrapped in coir fabric to provide short-term stability and long-term deformability.[5] Another style of bank toe that functions as a deformable bank, though on a different time scale, is a log toe, which is described separately in this chapter and in the *Log Toe and Revetments* section of the Natural Resources Conservation Service guidelines.[3]

Emergency

This technique is not recommended for use in emergency situations.

EFFECTS

If well-designed and constructed, this technique provides immediate and long-lasting streambank protection. Within several growing seasons, these treatments can support a diverse plant community; and, as vegetation matures, overhanging stream cover and undercut, root-reinforced banks may develop. Shrub plantings can provide roughness in flood flows, and trees will provide a long-term source of large woody debris.

Reinforced soil protection can be designed and constructed as either deformable or nondeformable treatments, which may result in lost-opportunity impacts and effects on the stream, depending upon the application.

DESIGN

Soil reinforcement typically employs four components:

1. toe protection,
2. an internal gravel drain,
3. soil reinforced lifts, and
4. revegetation.[2]

The toe foundation generally consists of rock, creating a stable base for the bioengineered bank to resist channel bed scour. However, deformable-toe alternatives, previously described under *Variations*, may also apply. The bottom elevation of the toe should extend to the maximum estimated depth of scour. The top elevation of the toe should be set high enough that the fabric-wrapped lifts resting on the toe will support the growth of perennial vegetation. An internal, gravel-filter drain is often included to provide subsurface drainage during rapid draw-down conditions following high-flow events.[6] A conceptual design drawing of soil reinforcement is shown in *Figure 6-36*.

Design Flow

The design of all components for a reinforced-soil project should be based on selected flow levels. P. B. Skidmore and K. F. Boyd describe various flow-based design criteria for deformable reinforced soil banks.[7] Selection of a toe-foundation treatment, fabric types, vegetation types, and bank slope will depend upon the design flows selected. Different bank components can be designed for different flows. For example, a deformable-toe treatment can be designed to withstand forces associated with a 50-year flow for the first five years and to be deformable thereafter, whereas the upper bank can be designed to withstand lesser flows. Similarly, all bank components can be designed to withstand the 100-year flow until vegetation becomes established, at which point stability will depend on the qualities of the established vegetation.

Fabric

Individual soil lifts, typically 0.5 to 1.5 feet tall, can be placed to create bank slopes ranging from 1:1 to flatter than 3:1. Lifts can be laid in horizontally or at a 10- to 15-degree backslope. They are frequently filled with fine-grained soils that will support the growth of vegetation. Bank treatments longer than the width of the fabric are constructed by overlapping adjacent strips of fabric by a minimum of three feet. The upstream fabric ends of fabric rolls should overlap downstream fabric ends like roof shingles to prevent the edges from being pulled up during flood events. The bottom and top edges of fabric lifts should be buried (embedded) a minimum of three feet. Fabric can be tensioned and secured using 18- to 24-inch-long, wedge-shaped wooden stakes, placed on three-foot centers along the upper edge and sides of a fabric wrapped lift.

Upstream and downstream ends of a treatment must be well-transitioned into nontreated banks and may consist of treatment ends that are keyed into the bank, covered with soil-filled riprap, or fabricated into carefully folded fabric corners. Transitions are discussed in more detail in the discussion on *Riprap* in this chapter.

Fabric used to build these lifts can be degradable, nondegradable, or a combination of both (see Appendix H, *Planting Considerations and Erosion-Control Fabric*). A fully degradable system can be created using two layers of degradable coir (coconut-husk fiber) fabric to encapsulate the soil lifts.[8] An outer layer commonly used is a heavy, 700-g/m^2, woven-coir, erosion-control fabric. This layer provides structural integrity to each lift and the bank itself. The use of an inner fabric prevents piping of fine material through the coarser outer fabric. The inner fabric is typically nonwoven coir, although burlap fabric or straw can also be used if more inexpensive, temporary materials are desired and seed establishment is expected to be rapid.

The entire structure should be designed to withstand bank shear forces during the establishment of vegetation. The anticipated lifetime of the coir fabric advertised by suppliers is five to seven years, although recent data suggesting a shorter life span should be considered.[8] A variety of nondegradable fabrics can also be used if vegetation establishment is uncertain or if erosional forces exceed the resistance provided by degradable fabrics.[9]

Plant Materials

A wide variety of plant materials can be used to ensure that vegetation successfully reinforces the soil lifts by the time any degradable fabric weakens. Typically, native grass seed is used because it is easily and inexpensively installed during construction and can provide both short and long-term bank reinforcement. It is recommended that cuttings of native willows or perhaps dogwood or cottonwood be placed (horizontally) between lifts during construction. Cuttings can also be planted into vertical or horizontal surfaces of lifts after construction (during the dormant season), but this tends to be more labor-intensive, as willows have to be physically pounded into the compacted soil lifts. Native herbaceous and woody plants grown in containers can also be planted into the exposed horizontal surfaces of lifts, although care should be taken to minimize the number of fabric strands cut to install plants. As with any revegetation effort, plant-species selection should be based on the site hydrologic regime, soil type, and rooting and establishment patterns.

The following is a summary of revegetation suggestions for this technique:

Seeding under erosion control fabric:

- Use a native seed mix with at least one quick-establishing species.
- After seed placement, ensure that seed is lightly compacted with a compactor, excavator bucket or the equivalent.

Planting horizontal cuttings:

- Cuttings are inexpensive and easily installed if placed horizontally between lifts during construction.
- Use cuttings that are three to five feet long (up to 15 feet long if necessary) and have a minimum diameter of 0.5 inches. Butt ends of cuttings should touch the back of the excavated trench and protrude only slightly from the lifts. Both diameter and species should be varied.
- Space cuttings no more than two feet apart; two to five cuttings planted per linear foot is about right.
- Orient cuttings perpendicular to stream flow, or at a slightly downstream angle.
- Place each cutting such that 75 percent of its stem is covered by the lift.
- Place one to three inches of soil around the rooting zone of the cuttings (optional).
- For better cutting survival during late-summer construction, consider using rooted cuttings grown in a biodegradable burlap sleeve.[10]

For additional information on revegetation considerations and planting methodology, refer to Appendix H.

CONSTRUCTION CONSIDERATIONS

An important consideration when using this treatment is that it requires great attention to detail during the design and construction phase. Failure to adequately consider the importance of seams, fabric overlaps, staking patterns and transitions between other treatments can lead to weak points and potential failures. Disturbance of existing riparian trees and shrubs should be kept to an absolute minimum during construction.

A greatly simplified, eight-step construction sequence for this technique is as follows:

1. Dewater the site as necessary to construct and install the toe foundation.
2. Excavate the subgrade.
3. Place the specified toe material from the depth of scour to an elevation consistent with the lower limit of perennial vegetation.
4. On the surface of the toe, place the selected fabric parallel to the stream and backfill with the selected fill material.
5. Compact the soil fill and place the seed. Lightly compact the soil around the seed.
6. Wrap the fabric over the compacted soil, tension the fabric and stake it.
7. Place the horizontal cuttings on the surface of the completed lift as described previously.
8. Repeat steps four through seven for each subsequent lift to create a terraced bank at a specified slope.[3,4]

Materials Required

Materials required for constructing a fabric-reinforced, soil-lift treatment may include, but are not limited to, the following (note - varying types of soil reinforcement will use varying types of fabric):

- rocks, logs or other toe protection;
- a gravel filter (as needed) to allow for internal soil drainage (refer to the discussion in this chapter on *Subsurface Drainage Systems*);
- three- to four-meter-wide, seamless, woven, erosion-control fabric for use as the outer layer;
- nonwoven or finely woven inner fabric to prevent soil piping through outer fabric layer;
- imported or native, loamy, soil fill, which will serve as a good growing medium;
- angled, 18- to -24-inch-long wooden stakes cut diagonally from 2 x 4s;
- herbaceous seed to be placed on the soil surface and beneath the erosion-control fabric; and
- rooted or unrooted willow or other cuttings for horizontal placement between lifts.

Construction generally requires the following equipment and labor:

- a crew of two to five laborers,
- an experienced construction supervisor,
- an excavator or bobcat to place and compact soil in the lifts,
- a compactor (hand-operated "bullwhacker" or the equivalent),
- construction forms (optional - see *Figure 6-36*), and
- a loader to haul and place soil and other materials.

For additional design and construction details on soil reinforcement refer to Natural Resources Conservation Service guidelines[3] and *Degradation Rates of Woven Coir Fabric Under Field Conditions*.[2] An article by the same author entitled, *An Innovative Method of Rooting Hardwood Cuttings for Use in Bioengineered Streambanks,*[10] describes an approach for propagating and installing horizontal willows that are designed specifically for soil reinforcement, and *Designing with Geosynthetics*[6] is an excellent reference for the design and placement of erosion-control fabrics in such applications.

Timing Considerations

Soil-reinforced banks must be constructed during low flow when dewatering is possible and when resident and anadromous fish are less likely to be impacted by construction activities. In order to install rock or log toe materials to the depth of scour, excavation within the channel bed will be necessary and, consequently, will require temporary dewatering systems. Dewatering allows for ease of installation and prevents siltation of the stream during construction. This can be accomplished with a coffer dam during low water.

Critical periods in salmonid life cycles such as spawning or migration should be avoided. Instream work windows vary among fish species and streams. Contact the Washington Department of Fish and Wildlife's Area Habitat Biologist for information on work windows (see Appendix B, *Washington Department of Fish and Wildlife Contact Information*). Further discussion on construction timing and dewatering can also be found in Appendix M, *Construction Considerations*.

It is by far more desirable to construct this type of bank during the plants' dormant season than in their growing season so that installed seed and cuttings will successfully germinate at the onset of the subsequent growing season. If this is not possible, certain adjustments regarding planting may be required. For example, during late-summer construction, it may be necessary to use rooted cuttings instead of other planting materials to get vegetation established quickly, and these and other plant materials may require irrigation.

Cost

Costs for installing soil-reinforcement treatments can range considerably due to the myriad of factors involved. Soil reinforcement requires a large amount of imported soil, rock, fabric, plantings and other materials; and it requires dewatering, excavation, materials management, equipment access and considerable hand labor. Fabric-encapsulated soil lifts range from $12 to $30 per linear foot for a single, one-foot-tall lift. Fabrics can cost from $0.50 to $3.00 per square yard for nonwoven material, uninstalled. For additional information about fabric costs, refer to Appendix H and Appendix L, *Cost of Techniques*. To learn more about the costs of other techniques used in concert with soil reinforcement, such as roughened-rock toes, log toes, subsurface drains, woody plantings and herbaceous cover, refer to the sections in this chapter that address them specifically.

In terms of time required, the typical construction pace for a fully completed single lift of fabric-encapsulated soil can range from 200 to 1,200 feet per day, depending upon site access, equipment, size and skill of labor crew, and many other factors.

BIOLOGICAL CONSIDERATIONS

Mitigation Requirements for the Technique

Soil reinforcement can be designed and constructed to be either deformable or nondeformable. Nondeformable treatments will result in long-term lost opportunities for spawning and rearing habitat, gravel recruitment and recruitment of large woody debris, which must be mitigated. Deformable treatments result in short-term lost opportunity impacts caused by construction activities; these also must be mitigated. Refer to Chapter 4, *Considerations for a Solution* and Matrix 3 in Chapter 5 for additional guidance concerning mitigation.

Mitigation Benefits Provided by the Technique

One of the main benefits of deformable, soil-reinforcement bank protection is that bank stability and erosion control are provided while also creating conditions conducive to the establishment of dense native vegetative cover. By itself, this technique does not provide any mitigation benefit.

RISK

Habitat

Because this technique requires considerable earthwork and excavation, temporary impacts during construction can be considerable, but it should be emphasized that these impacts are generally only short-term. To reduce habitat risks associated with construction activities, restrictions are placed on the allowable construction period. Best-management practices for sediment and erosion control must be implemented.

Infrastructure

This technique has been successfully implemented in streambank-protection projects to protect infrastructure. Success is dependent upon using this technique in combination with other biotechnical techniques and, in some cases, toe protection.

Reliability/Uncertainty of Technique

This technique can be highly successful if designed and implemented by experienced designers and qualified contractors. Properly applied design criteria and careful engineering of all project components can result in a high level of certainty for project success and long-term bank protection.

MAINTENANCE

Soil-reinforcement treatments generally require little maintenance when subjected to flows less than or equal to their design flow. However, maintenance needs may include some of the following: temporary irrigation and reseeding or replanting of woody-plant materials.

MONITORING

Monitoring soil-reinforcement treatments should involve survey and visual inspection - including regular photo documentation of the integrity of the reinforced soil structure and associated vegetative components. Monitoring should focus on looking for potential weak points in the design, such as scour at the toe of the structure, plant growth, fabric integrity, transitions between treatment methods and transitions between treated banks and undisturbed upstream and downstream banks.

Monitoring frequency should be annual for a minimum of five years, or the anticipated design life of the structure and should be conducted during low flows when visual inspection of the toe of the structure is possible. Additionally, monitoring should be conducted following any events that equal or exceed the one-year flow during the first three years following construction. For further discussion of monitoring-plan development and monitoring methods, refer to Appendix J, *Monitoring*.

Impacts to the channel and to habitat must be carefully monitored. Changes to available habitat should be documented on a schedule dictated by fish life cycles. For a comprehensive review of habitat-monitoring protocols, refer to Johnson, et al.[11] Habitat-monitoring protocols will likely require a monitoring schedule that is more comprehensive than that required for the integrity of the structure.

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a. Soil Reinforcement lifts with barbs and rock toe. Salmon Creek, Tributary to Columbia River. 1997.

c. Soil Reinforcement lifts with rock toe. Touchet River. 2000.

b. Soil Reinforcement lifts with log and rock toe. Salmon Creek, Tributary to Columbia River. 1997.

d. Soil Reinforcement lifts with woody plantings. Cedar River side channel.

Figure 6-35. Various applications of soil reinforcement throughout Washington State.

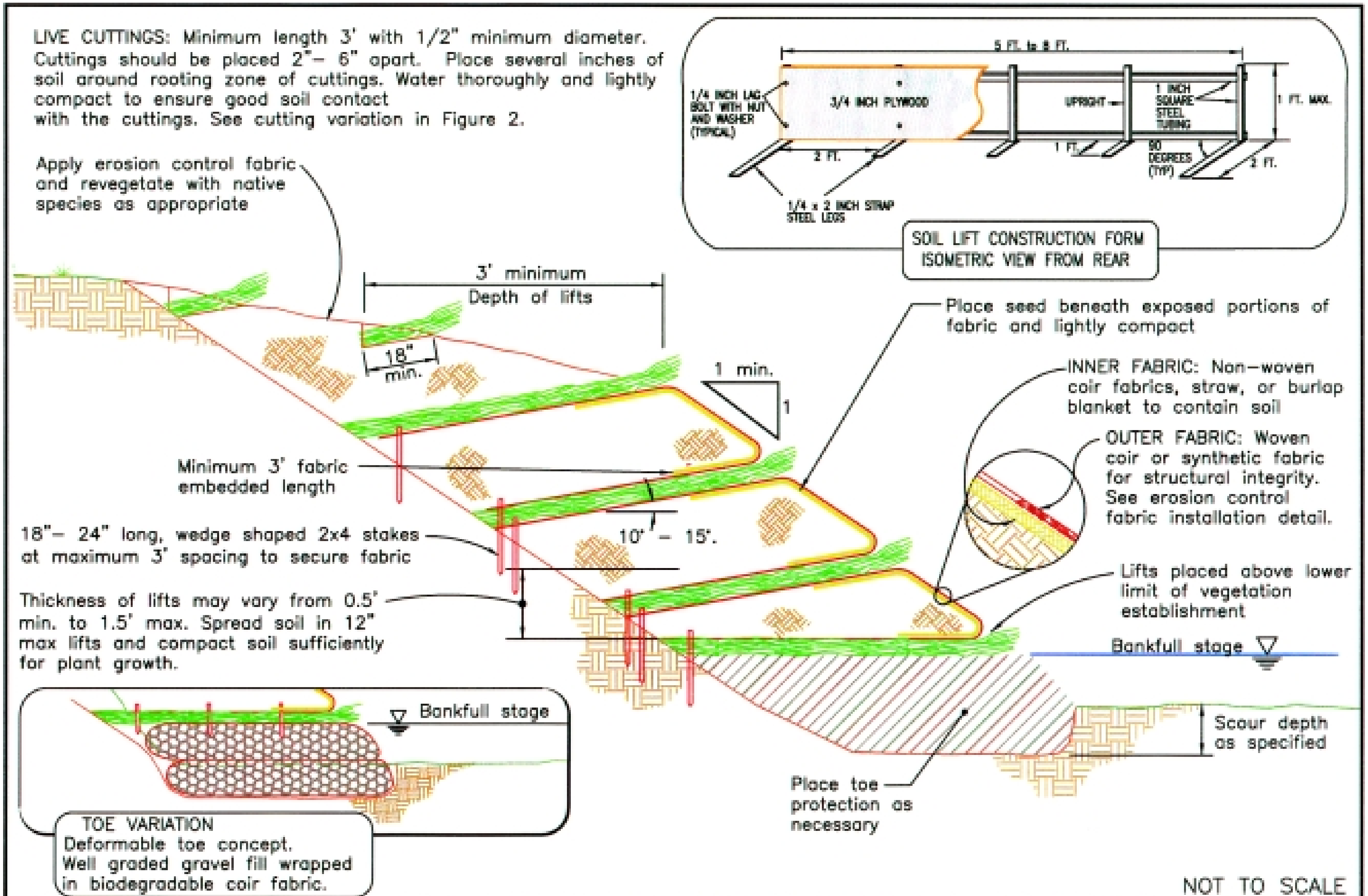

FIGURE 6–36

SOIL REINFORCEMENT CONCEPTUAL DESIGN

INTEGRATED STREAMBANK PROTECTION GUIDELINES
www.wa.gov/wdfw/hab/ahg/ispgdoc.htm

DESCRIPTION

Coir logs are long, sausage-shaped bundles of coir (coconut fiber), bound together with additional coir or synthetic netting. Typically planted with riparian vegetation, coir logs provide biodegradable stabilization to streambanks. The coconut fiber core has a high tensile strength, relatively slow decomposition rate (seven to 12 years) and good moisture-retention properties. When used in streambank construction, coir logs can trap stream sediments during overbank flows, which further enhances their function as a growth medium for streamside plants. *Figure 6-37* (at the end of this technique discussion) shows an application of coir logs.

Coir logs are known by several trade names, including Biologs®, Koirlogs® and BioD-Roll®.

APPLICATION

Coir logs are commonly used as a temporary measure to stabilize the bank toe while riparian vegetation develops to provide bank support. They are typically staked in a single row at the base of low (one- to three-foot-high) streambanks on small streams. However, in limited circumstances, successful applications of coir logs have been made on much higher banks of large streams. Once the coir log is in place, the bank behind the log can be reshaped to a stable configuration and planted with native riparian vegetation. In this configuration, the logs provide protection against hydraulic forces at the toe of the bank. Properly installed, coir logs may also provide a good growth medium for riparian plants and are usually planted with herbaceous or woody vegetation.

The most appropriate application of coir logs without supplemental toe protection is at the base of streambanks of relatively shallow, low-energy and possibly braided streams, where toe erosion is observed (see Chapter 2, *Site Assessment* and Chapter 3, *Reach Assessment* for more information on the mechanisms and causes of bank failure). Examples include streams with low seasonal variation in stage, such as spring-fed or wetland-dominated streams and those with very small or low-elevation watersheds. This application is particularly appropriate where channels have become over-wide due to grazing or other sedimentation impacts, and it can be used to create channel-margin wetlands.

If coir logs are used on higher-energy streams, it is recommended that they be used in combination with toe protection below the coir log. The choice of toe protection will vary with the degree of durability required at the site and the estimated shear stress to which it will be subjected. On high-energy streams, a hard toe made of stone or similar material is often used. On low-energy streams, a second coir log, dead-brush layer or other type of soft toe may be sufficient to prevent undercutting of the treatment. The toe should extend down to the estimated depth of scour.

An advantage of coir logs over some other bank treatments is that they can be transported to the site and installed without the use of heavy equipment, making them a valuable tool where site access is limited.

As with any technique that relies on vegetation to provide long-term bank stabilization, coir logs should only be used in areas that can support vegetation and where vegetation, in combination with any toe protection, will provide all necessary long-term bank strength. Coir logs are not appropriate under bridges, areas subjected to heavy foot and animal traffic, or in areas where poor water or soil quality will inhibit plant growth. The top of the coir log should be placed at or above the lower limit of perennial vegetation.

There are several inherent site limitations to coir-log treatments placed without supplemental toe protection. As a single log installed at the base of a streambank, the log will provide a degree of protection to the base of the bank, but may offer little to no protection against undercutting by scour. A stream with even a moderate amount of erosive potential could readily scour under the logs and destabilize the bank. This will often rule out the use of coir logs as a stand-alone treatment on high or unstable banks and in high-energy situations.

On the other hand, coir logs in combination with bank-toe protection is a possibility where the mechanism of bank failure is scour. However, before a hard toe is used with a coir-log treatment, preparations to adequately stake and secure coir logs must be made; staking into rock toes is often difficult, if not impossible.

On stream treatments where bank failure can be attributed to mass failure or avulsion, coir logs, with or without supplemental scour protection, are not an appropriate bank-protection technique. The screening matrices in Chapter 5, *Identify and Select Solutions* provide more guidance on the applicability of coir logs based on the specific mechanism of failure and causes of streambank erosion.

Another potential site limitation of this technique is that coir logs tend to form relatively uniform and smooth streambank edges and may not provide the immediate roughness and cover that is desired from a hydraulic or fish-habitat perspective. This trait may also limit its application where smooth banks are already creating excessive, low-flow velocities. Eventually large, woody roots of trees and shrubs would be expected to colonize the coir log and bank, thus creating the desired roughness and bank diversity, but such benefits take many years to manifest. Consequently, this technique is recommended where immediate bank roughness is required only if it is used in conjunction with a roughened toe.

While planting into coir logs is recommended and generally very successful, it should be noted that the water-holding capacity of coir logs is not as good, for example, as a comparable volume of loamy soil. Thus, establishment of riparian plants in coir logs can be difficult on mid to upper banks of droughty streambank sites, especially in eastern Washington.

Variations

Log Terraces

When used as a buttress at the toe of streambanks, an edge of coir fabric can be anchored under a coir log or laced to the log using strong coir or synthetic twine. Soil is then placed landward of the log, and fabric is wrapped over the fill material and staked in place to provide erosion protection for backfilled soils until vegetation establishes. Another excellent application of coir logs is to install them at intervals up a sloping bank surface to create steps or terraces to control surface erosion and aid plant growth. Another variation is to stack rows of coir logs upon one another to form a tall bank face. When stacking coir logs, the upper log should be placed above and behind the first log and the two logs should be laced together with stout coir or synthetic twine, laced every six inches and knotted at a minimum of every three linear feet to prevent separation of the logs.

Sediment Control

Coir logs can be used as sediment-control devices at the toe of stable, but nonvegetated streambanks on small and low-energy streams. While the logs can trap sediment running off of the bank, coir logs provide no protection from sediment inputs to the stream during high-flow events when the log is over-topped.

Alternatives

Straw Bales and Straw Logs

Low-cost alternatives to coir logs are hay or straw bales. Straw will tend to biodegrade more rapidly than coir, and this factor should be taken into account when considering using it. Unless applied in low-gradient, spring-fed creek environments, bales should be wrapped in coir fabric for added integrity. Straw logs are somewhat similar in appearance to coir logs, but they provide surface sediment control and are considered a biodegradable replacement for silt fences. Straw logs are not recommended for streambank applications.

Emergency

Coir logs are generally not applicable in emergency situations.

EFFECTS

Coir logs, if properly applied, provide deformable streambank protection and sediment retention. Within several growing seasons, these treatments can support a functional floodplain that, in turn, supports a diverse plant community and overhanging stream cover. Shrub plantings behind or within coir logs can provide roughness in flood flows and installed or colonizing trees will provide a long-term source of large woody debris. If used to narrow the cross section of an over-widened stream, sediment transport within the channel and sediment retention in the floodplain bench may be improved. This may make stream gravels more suitable for spawning.

If biodegradable coir logs are used, there are no long-term negative impacts from their installation. However, if coir logs with synthetic materials are installed, the breakdown time of the synthetic components may be on the order of decades.

DESIGN

A conceptual design of a typical coir log is shown in *Figure 6-38*. Because coir logs do not provide long-term bank stabilization, they should only be used in situations where vegetation will provide all necessary long-term bank strength.

Most manufacturers supply guidelines regarding maximum velocity and/or shear that their products can withstand. When considering such information, the designer should keep these observations in mind:

- tests conducted by manufacturers are generally short-term and do not reflect natural conditions including long flood durations and product degradation over time; and
- coir logs may withstand higher hydraulic forces than laboratory tests suggest by securing systems and surrounding in situ bed and bank materials.

Installing and Securing Coir Logs

Like many bank-revetment systems, weak points in coir-log revetments lie at the transitions between the logs and the securing system. The following are eight design/installation guidelines, based in part on Natural Resources Conservation Service recommendations[1] (note that the following procedures do not take into account supplemental bank-toe protection):

1. As with any bank-protection treatment, the coir-log technique should start and end in a stable reach.
2. Excavate a shallow trench for the log at the toe of the bank slope. The bottom of the trench should be slightly lower than the streambed level.
3. Inspect all coir logs for breaks in the netting, and repair all breaks with natural or synthetic rope prior to log installation. Place the logs in the trench such that the ends are butted firmly together. The logs should be laced together, end-to-end, with coir or synthetic rope to create a continuous length. End-to-end lacing may be completed either before or after placement in the stream, whichever is easiest. The upstream and downstream ends of the continuous length of coir logs tend to be weak spots and should therefore be buried three to five feet laterally into the bank to protect against erosive forces.
4. When properly installed, the upper surface of the roll should be parallel to the water surface at or above the ordinary high-water line and within the zone of perennial vegetation. Cut-and-fill adjustments can be made as needed, using only hand tools wherever possible, to seat the roll so that it lies smoothly at the correct elevation.
5. Secure the coir log in the trench by driving stakes (2 x 2 x 36 inches) between the binding twine and the inner log material on either side of the log. Pairs of stakes (one stake on each side of the log) should be installed at intervals of one to four feet along the length of the log, depending upon anticipated hydraulic forces. The tops of the stakes should not extend above the top of the log. All stakes should have notches that prevent laced twine from sliding off the ends of stakes.
6. In areas that will experience wave or ice action, 16-gauge wire should be used to secure the log. To install the wire, notch the outside faces of each pair of stakes slightly below the top of the log and install the wire through the notch.

7. Once the logs are secured, soil should be backfilled on the bank side of the log, and the bank should be reshaped as necessary. Planned surface treatments and plantings should then be installed on the bank. Care should be taken to disturb as little soil as possible outside the work area and to avoid damaging any existing trees and shrubs on or near the bank.

8. Rooted herbaceous plantings should be installed into the top or sides of the coir log. Alternatively, live cuttings can be installed through the log into the underlying substrate if a means to mechanically pierce the logs is available.

Planting in Coir Logs

Planting vegetation into coir logs can be difficult because of the tight fabric strands and the high density of the coir filling. Some manufacturers have responded to this problem by offering logs with three- to four-inch-deep, premade holes that make insertion of plant materials into the logs easier. Similarly, insertion of stakes through the logs can be much more difficult than might be expected (this partially explains why stakes are placed along the edges of coir logs); however, if a mechanical device is used to punch holes through the dense fill of coir logs, stout willows can be planted through the log for use as both staking and woody-plant cover. Other bioengineering techniques can also be used with coir-log applications, including brush layers and fascines. See the discussion in this chapter addressing *Woody Plantings* and Appendix H, *Planting Considerations and Erosion-Control Fabric* for more information.

BIOLOGICAL CONSIDERATIONS

Mitigation Requirements for the Technique

There may be some mitigation concerns for this type of treatment, since limiting channel migration can result in loss of overhanging banks and gravel sources. However, because coir logs are biodegradable and deformable, these effects tend to be short-term, as long as any toe protection that is added is also deformable.

Additionally, there may be impacts to fish habitat in terms of sedimentation during installation of coir logs; but, because impacts also tend to be temporary, mitigation is generally not required. Since coir logs can be installed using hand tools and because they trap sediment, they are less impacting in terms of sediment than many other types of streambank protection. To reduce habitat risks associated with construction activities, restrictions are placed on the allowable construction period. Best management practices for sediment and erosion control are also required. Refer to Chapter 4, *Considerations for a Solution* and Matrix 3 in Chapter 5 for more detail on mitigation needs for this bank treatment.

Mitigation Benefits Provided by the Technique

Coir-log installation avoids mitigation needs for long-term impacts. A benefit of this technique is that bank stability and erosion control are provided while also creating conditions conducive to the establishment of dense, native-vegetative cover. Coir logs can be used to narrow the cross section of small, over-widened creeks, creating a functional floodplain and potentially improving the quality of spawning gravels. Refer to Matrix 3 in Chapter 5 for more detail on the mitigation benefits of this technique.

RISK

Habitat

The use of coir logs poses no long-term risk to habitat. When used to create low banks in relatively low-energy systems, coir logs produce a bank very similar in appearance and function to natural banks, once vegetation is established. This treatment can be used to transition into zones of existing adjacent vegetation.

Infrastructure

Coir logs pose no risk to infrastructure unless they are used incorrectly, which could result in continuing bank failure. It may be difficult to safely transition coir-log bank treatments into adjacent infrastructure such as bridges and culverts.

Reliability/Uncertainty of Technique

There is uncertainty in all treatments that rely on vegetation for long-term strength. An advantage coir logs have over other biodegradable products such as erosion-control fabric is that, because of their bulk and thickness, they tend to biodegrade relatively slowly. However, it is essential that coir logs be used at sites and within specific elevation ranges where aggressive plantings will succeed. Poorly executed site selection, log placement or revegetation techniques may leave a coir-log treatment inadequately vegetated and vulnerable to erosion as the coir log degrades.

Successful implementation requires a substrate suitable for installation of wooden stakes as well. Bedrock and substrate with a large amount of rock, such as a rock toe, may limit or prevent staking and securing of coir logs.

CONSTRUCTION CONSIDERATIONS

Materials Required

Depending upon the manufacturer, coir logs are available in a range of diameters, between six and 20 inches, and a range of densities, between six and nine lbs/ft^3. Commonly available lengths are 10 and 20 feet. The type of netting used to bind the coir logs can be either coir or synthetic (wire or twine). Higher-density coir logs provide greater stability and longer life than logs packed with lower densities of material. Synthetic netting is recommended over coir netting for banks subject to higher levels of shear stress and where conditions are such that the growth of vegetation will be limited in the first growing season. The range of conditions appropriate for each product should be based on the manufacturer's guidelines and the professional experience of the treatment designer and installer.

Simple coir-log installation requires the logs themselves, wooden stakes, biodegradable or synthetic rope, and rooted vegetation or cuttings. As mentioned above, wire or twine may be required as an added measure to secure logs in areas subjected to wave or ice action. Often, coir logs can be installed by hand, but heavy equipment such as an excavator may be useful on larger applications.

Timing

Coir-log installation should be undertaken when water levels are low. Ideally, this can also coincide with the riparian-plant dormant season to maximize the success of planted vegetation. When this timing is not possible, vegetation should be installed during the first planting season after bank construction. Coir logs can often be installed without dewatering in low flow conditions; however, dewatering may be required if excavation for supplemental toe protection is necessary. For further discussion of construction timing, refer to Appendix M, *Construction Considerations*.

Cost

The cost of coir logs is between $6 and $12 per linear foot, depending upon their diameter and density. Installed coir-log toe treatments with plantings cost about $26 per linear foot.[2] A similar treatment with the addition of erosion-control fabric and willow bundles runs about $43 per linear foot.[2] The cost will vary tremendously depending on what is done for bank-toe treatments under the logs and for upper-bank treatments.

Costs for implementing this treatment may also include gaining access to the site, dewatering, excavation, importing fill, and materials and installation of any additional toe materials and upper-bank treatments. For additional information on the costs associated with this technique, refer to Appendix L, *Cost of Techniques*.

MAINTENANCE

Because the long-term integrity of this bank-stabilization technique relies on the roots and shoots of vegetation, installed plantings may require irrigation, weed control and/or protection from grazing. The anchoring system may also need maintenance or replacement, with special attention paid to the wire or twine laced between stakes and over the logs.

MONITORING

Monitoring is an essential tool to evaluate project success, to ensure that project objectives are met and to determine if maintenance is needed. Monitoring activities should focus on potential weak points in the design, such as at transitions between undisturbed and treated banks and between different bank treatments. Monitoring should include regular photo documentation. Additionally, monitoring coir logs should be coordinated with monitoring associated bank-protection techniques, which may include upper-bank revegetation and other bank-toe treatment.

Monitoring should include detailed as-built surveying and photo documentation of the project area, as well as upstream and downstream reaches to evaluate performance relative to design. Details on developing a monitoring plan are discussed in Appendix J, *Monitoring.*

The monitoring plan for coir-log treatments should be designed to evaluate the integrity of the securing system, the integrity of the coir material over time and the success of the vegetative component incorporated into the coir log toe. Monitor the physical integrity of installed logs and securing systems in response to the first few high-flow events to which the bank treatment may be exposed. At a minimum, coir logs should be inspected for movement (indicating loose installation) or loosened securing components after flow events equivalent to the one-year flow for the first three years.

It is also important to monitor vegetation success. As with most biotechnical bank treatments, monitoring should be most intensive during the first year after installation and can be scaled back to a single, annual monitoring event in subsequent years. For further discussion of monitoring methods, see Appendix J.

For a comprehensive review of habitat-monitoring protocols, refer to Johnson, et al.[3] Habitat-monitoring protocols will likely require a monitoring schedule that is more comprehensive than that required for the integrity of the structure.

REFERENCES

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Figure 6-37. Coir Logs. Zaccuse Creek, Tributary to Lake Sammamish. 2000. Source: King County Department of Natural Resources.

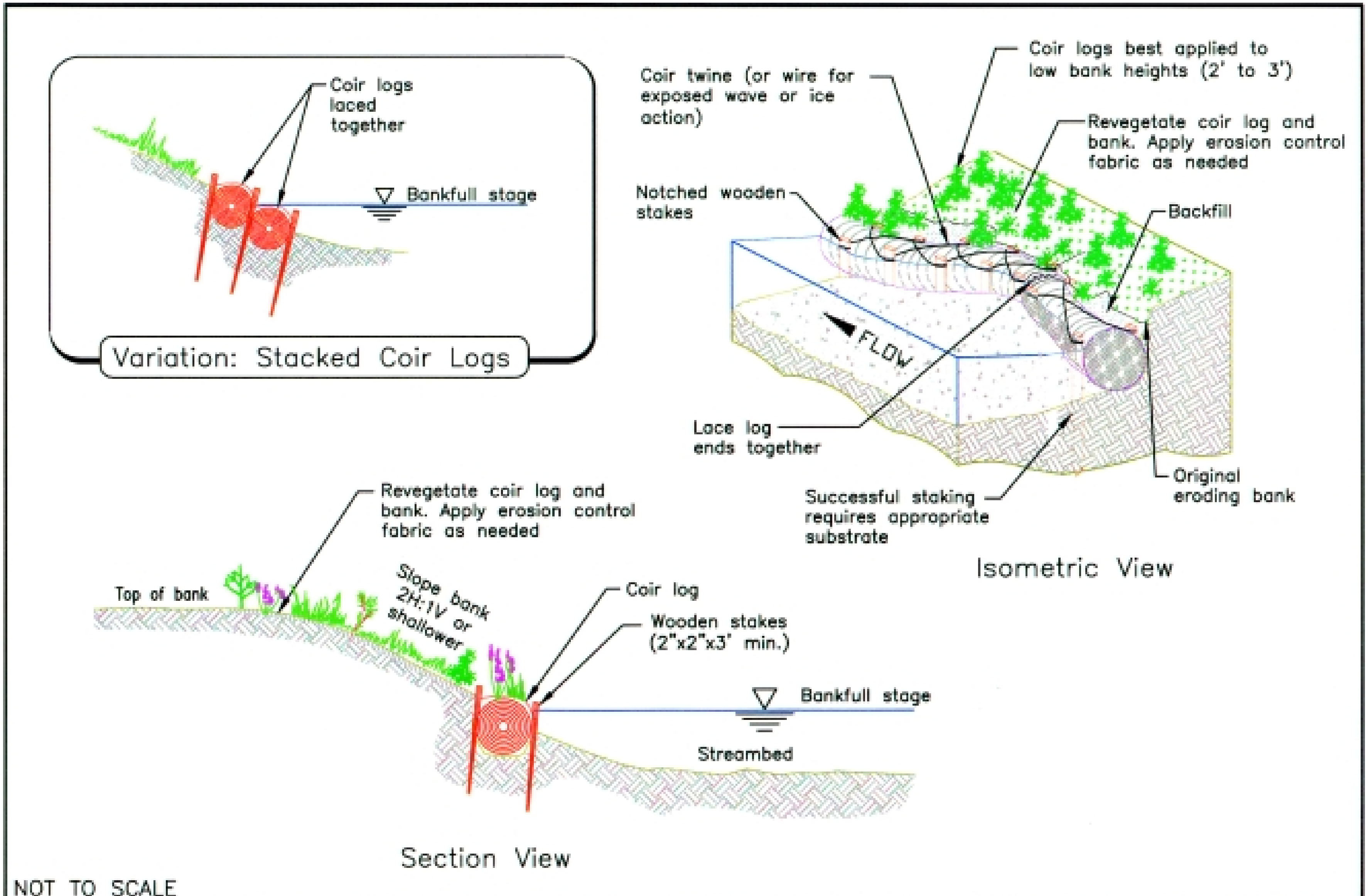


FIGURE 6–38

COIR LOGS CONCEPTUAL DESIGN

INTEGRATED STREAMBANK PROTECTION GUIDELINES
www.wa.gov/wdfw/hab/ahg/strmbank.htm

Bank Reshaping

Biotechnical Techniques

DESCRIPTION

Bank reshaping stabilizes an eroding streambank by reducing the angle of its slope, without changing the location of its toe. Excavating the bank to reshape it changes the cross-sectional geometry for that segment of the stream. Bank reshaping is usually done in conjunction with other bank-protection treatments, including revegetation of the excavated bank and installation of toe protection and erosion-control fabric. *Figure 6-39* shows various applications of bank reshaping throughout Washington State.

APPLICATION

This technique is commonly applied along streambanks that are vertical, eroding and positioned in the outside bends of a stream, where they have been undercut and are failing in cohesive masses due either to toe erosion or to mass failure. Because bank reshaping provides greater cross-sectional area in a channel and it accommodates revegetation well, it is also a useful bank-protection technique for use in aggrading reaches. The ability to reshape banks may be limited where access is difficult for heavy equipment, and it may be unsuitable where mature riparian vegetation or infrastructure (such as roads, housing or bridges along the upper bank) stand in the way.

Bank reshaping is an effective way of addressing over-steepened banks resulting from virtually any mechanism of failure, but it generally requires that other treatments be incorporated as well. Bank reshaping can be especially effective when used in combination with some form of temporary or permanent toe hardening. Bank reshaping should not be applied at a reach level to prevent avulsion because it does not address the actual mechanism of failure. The problem would simply continue to occur.

Additional guidance on the applicability and limitations of bank reshaping based on both the site mechanism of failure and reach conditions can be found in Matrices 1 and 2 in Chapter 5, *Identify and Select Solutions*. Chapter 2, *Site Assessment* and Chapter 3, *Reach Assessment* provides information on the application of assessing the causes of erosion.

Emergency

Attempting to reshape banks during a flood is not recommended because of the exposure of saturated and unprotected soil to the floodwaters.

EFFECTS

By definition, bank reshaping consists of changes to channel bank slope and cross-section configuration. It generally results in increased channel cross-sectional area (see Appendix F, *Fluvial Geomorphology*). Bank reshaping is a necessary component of some of the biotechnical practices and structural remedies described in these guidelines. In addition, it provides a number of benefits to the stream system. First, making the slope shallower adds stability and reduces the banks susceptibility to failure. Second, the additional bank surface area effectively creates more roughness in the cross section and dampens the effects of secondary currents in river bends. The added roughness and cross-sectional area decreases average and local velocities, slows erosion and increases the likelihood of sediment deposition. Third, modifying the channel bank slope makes it easier for vegetation to take hold, and a shallower slope facilitates planting and long-term maintenance. Fourth, reducing vertical bank slopes that have excessive drainage improves soil moisture conditions. Fifth, bank sloping may improve recreational access to the river, and it reduces safety hazards. Bank sloping often results in an initial loss of undercut banks, which provide good fish habitat; however, undercut banks can be integrated into bank-toe design or may occur naturally once vegetation is well established.

DESIGN

Designs associated with bank reshaping are site-dependent. On small creeks, or where infrastructure is not at risk, reshaped banks may be accomplished with relatively simple design and planning. In other instances, bank reshaping may require extensive analysis, design and preparation of complete plans and specifications. Principal components of bank-reshaping design may include revegetation, surface soil-erosion control and toe protection. A conceptual design drawing is shown in *Figure 6-40*.

Bank reshaping has several components, including excavation of over-steepened bank materials, placement or transport of excavated materials, and the recontouring or reshaping of excavated streambanks. Often, recontouring is the most difficult of these phases because it requires the combination of an understanding of fluvial processes, a skilled excavator operator and subtle grade breaks. A reshaped bank must transition well from adjacent treated or untreated banks so that the erosive forces of flowing water will not be concentrated on a specific area.

During the design and construction phase, be sure to minimize the removal or root disturbance of existing riparian trees and shrubs. They play many important roles in stabilizing banks and providing fish habitat, and they need to be protected.

Slope Grading

The actual grading or slope configuration related to this technique varies. At the simplest, banks can be graded to a stable slope and planted with tree shrubs and native seed (see Appendix H, *Planting Considerations and Erosion-Control Fabrics*).

The constructed slope of the bank may also vary, depending upon the height of the bank, soils strata, seasonal groundwater conditions and seepage from the bank, revegetation needs for soil and moisture conditions, and availability of land. Soils, vegetation and hydrologic conditions should be clearly understood for the site, and appropriate expertise should be consulted on the subjects.

To mimic natural banks, the slope should be varied along the length of a stream reach so that a constant slope is avoided. One approach to add variability to both habitat complexity and slope is to use large woody debris in the toe of a resloped bank. Where width allows, it may also be possible to incorporate a nearly horizontal bench or terrace into the reconfigured slope. Another variation is to create shallow swales or depressions on the upper surface of a resloped streambank to create micro-sites that will support diverse vegetation types.

Revegetation and Soil-Erosion-Control Fabric

On small streams, placement of salvaged sod or other types of herbaceous and woody vegetation on the reshaped bank may be sufficient to prevent surface erosion and to establish vegetative cover. However, there is always the risk that bare soils will erode as a result of either rainfall or high flows before vegetation becomes established. At more severe sites, a recontoured bank may need to be covered with erosion-control fabric or other forms of bioengineered bank protection. In general, the need for erosion-control fabric on reshaped banks should be based on the scale of the project, a thorough understanding of the mechanisms of failure at work and the risk of erosion should vegetation not become established. Topsoil may have to be placed over the cut bank to improve revegetation conditions. Topsoil might be placed over the entire area to be planted or in zones for specific vegetation types. See Appendix H for further discussion of these topics.

BIOLOGICAL CONSIDERATIONS

Mitigation Requirements for the Technique

Replanting vegetation on the reshaped banks may be the primary habitat mitigation needed. Additionally, if a nondeformable bank-toe treatment is used in combination with reshaping, then the lost opportunity for recruitment of gravel and large woody debris will require mitigation.

Because this technique requires considerable earthwork and excavation, temporary impacts during construction can be considerable. To reduce habitat risks associated with construction activities, restrictions are placed on the allowable construction period. Best management practices for sediment and erosion control must also be implemented.

Considerable volumes of excavated soil can be generated by a bank reshaping project. The proper disposal of those soils should be planned for so they do not jeopardize other habitats.

Refer to Chapter 4, *Considerations for a Solution* and Matrix 3 in Chapter 5 for more detail on mitigation needs for this bank treatment.

Mitigation Benefits Provided by the Technique

This technique will reduce sediment input to a stream once banks become revegetated. Stable, low-gradient banks enable the re-establishment of native, riparian plant communities to occur more quickly than if left alone and may improve bankline habitat complexity.

RISK

Infrastructure

Bank reshaping has no impact on infastructure.

Reliability/Uncertainty of Technique

Like many other streambank treatments, the reliability of this technique depends upon the quality of its design and implementation. If modes of bank failure are not addressed and reshaped bank surfaces not adequately protected, the site will likely continue to erode. And, if transitions between treated areas and untreated areas are not dealt with properly, this technique is prone to failure.

CONSTRUCTION CONSIDERATIONS

Materials Required

Bank reshaping, at a minimum, requires an excavator or equivalent piece of heavy machinery for earthwork. If excavated material needs to be moved a farther distance than the reach of an excavator, additional equipment such as loaders, dozers or dump trucks may be needed to haul or move material. The only imported materials required may be topsoil or soil amendments, seed and locally harvested or salvaged plant materials. On more complex projects, materials for use in toe reinforcement, erosion control and planting of nursery-grown vegetation may also be needed. Careful consideration should be given to the potential for soil eroding from the bank before vegetation has a chance to become established. For further discussion of construction considerations, see Appendix M, *Construction Considerations.*

Timing Considerations

In most regions of Washington, fall is the best time for this type of work; flow levels are low; soils are generally dry, and most plant materials can be safely installed. The survival of plantings may require a spring construction period and/or an extended construction period to appropriate planting seasons. Any instream work will depend upon resident and anadromous fish presence and may require dewatering. Instream work windows vary among fish species and streams. Contact the Washington Department of Fish and Wildlife's Area Habitat Biologist for information on work windows (see Appendix B, *Washington Department of Fish and Wildlife Contact Information*). For further discussion of timing considerations, see Appendix M.

Cost

In its simplest form, bank reshaping is one of the least expensive types of bank-reconstruction techniques. Bank reshaping costs typically vary between $10 and $45 per foot of streambank treated. Revegetation costs for reshaped banks may vary between $1,000 and $5,000 an acre, depending upon plant materials and soil amendments applied. Topsoil added may cost between $10 and $15 per cubic yard. Site-specific factors such as site access, quantity and haul distance of excavated material, and the degree to which erosion-control products and natural, wood materials are integrated into the reconstructed bank will result in site-specific and wide-ranging costs. If dewatering is necessary, costs will increase considerably. For further discussion of costs, see Appendix L, *Cost of Techniques*.

MAINTENANCE

Maintenance requirements for reshaped banks are relatively minimal, since this type of treatment is generally self-sustaining. Maintenance may involve care of vegetation, including irrigation, weed control, mowing, plant replacement and protection of vegetation from beaver damage, depending upon the site.

MONITORING

Monitoring is an essential tool to evaluate project success, to ensure that project objectives are met and to determine if maintenance is needed. Monitoring activities should focus on potential weak points in the design, such as transitions between undisturbed and treated banks and between different bank treatments. Periodic photo documentation should be included. The long-term success of bank-reshaping treatments will ultimately depend upon revegetation efforts and, if toe protection is incorporated, the integrity of toe-protection methods.

Monitoring should include detailed as-built surveying and photo documentation of the project area, including upstream and downstream reaches, to allow for evaluation of performance relative to design. Details on developing a monitoring plan are discussed in Appendix J, *Monitoring*.

Monitoring should involve inspecting for any signs of erosion, including at the toe of the bank, and should include photo documentation at each monitoring interval. Vegetation coverage and survival, weed establishment and response of the stream to the modified configuration should also be monitored relative to revegetation success criteria. Monitoring should include structural and functional evaluation of any habitat mitigation required.

Monitoring frequency should be most intensive (monthly) during the first few seasons following construction but may be reduced to annual monitoring in subsequent years. Additionally, monitoring should be conducted following any events that equal or exceed the one-year flow during the first three years following construction. For further discussion of monitoring methods, refer to Appendix J. For a comprehensive review of habitat-monitoring protocols, refer to Johnson, et al.[1] Habitat-monitoring protocols will likely require a monitoring schedule that is more comprehensive than that required for the integrity of the structure.

REFERENCES

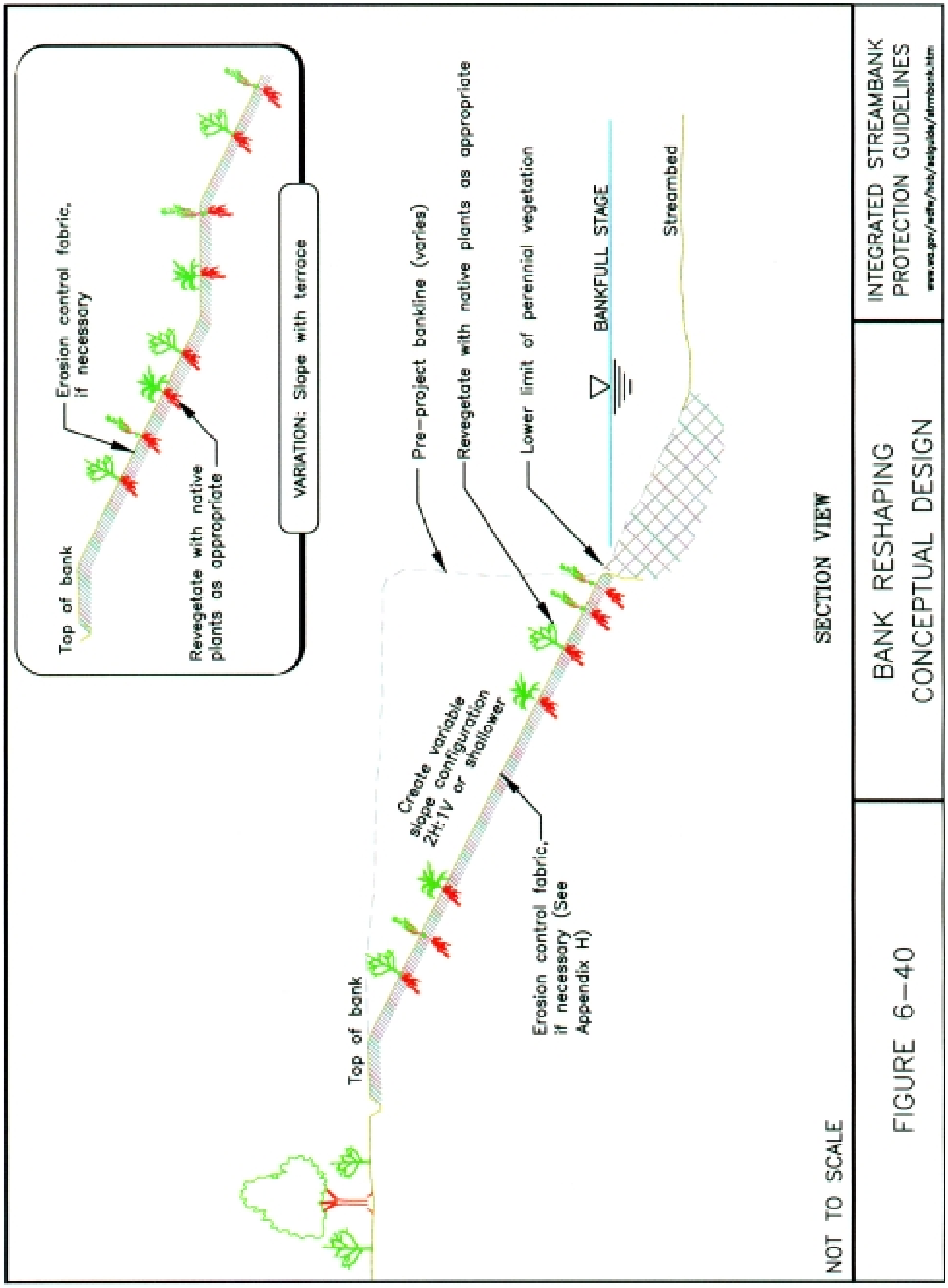
1 Johnson, D. H., N. Pittman, E. Wilder, J. A. Silver, R. W. Plotnikoff, B. C. Mason, K. K. Jones, P. Roger, T. A. O'Neil and C. Barrett. 2001. Inventory and Monitoring of Salmon Habitat in the Pacific Northwest - Directory and Synthesis of Protocols for Management/Research and Volunteers in Washington, Oregon, Idaho, Montana, and British Columbia. Washington Department of Fish and Wildlife, Olympia, WA.

a. Bank reshaping. Unidentified creek in Montana.
Source: Inter-Fluve, Inc.

b. Bank Reshaping. Chimacum Creek, Tributary to Admiralty Inlet, Puget Sound. 1996.

c. Bank Reshaping. Touchet River.

Figure 6-35. Various applications of bank reshaping throughout Washington State.



Top of bank
Erosion control fabric, if necessary
Revegetate with native plants as appropriate
VARIATION: Slope with terrace
Pre-project bankline (varies)
Revegetate with native plants as appropriate
Lower limit of perennial vegetation
BANKFULL STAGE
Streambed
Top of bank
Create variable slope configuration 2H:1V or shallower
Erosion control fabric, if necessary (See Appendix H)
SECTION VIEW
NOT TO SCALE
FIGURE 6-40
BANK RESHAPING CONCEPTUAL DESIGN
INTEGRATED STREAMBANK PROTECTION GUIDELINES

Subsurface Drainage Systems

Internal Bank-Drainage Techniques

DESCRIPTION

Subsurface drainage systems, installed under or behind surface bank treatments, such as riprap or soil reinforcement, alleviate saturated soil problems in streambanks, side slopes and embankments. Subsurface drainage systems increase slope stability by decreasing soil-pore pressure. Subsurface drainage systems can be installed in a variety of configurations, including chimney drains, collection drains and gravel seams. These may include gravity or pumped systems.

APPLICATION

Subsurface drains are rarely installed as a stand-alone treatment, but they can be useful when used in combination with other treatments if any or all of the following conditions exist:

- rapid drawdown situations;
- high banks;
- steep banks;
- signs of slumping, seeps or soil creep; or
- poorly-draining soils.

Subsurface drains are often appropriate on eroding banks where the mechanism of failure is subsurface entrainment, which may be caused by poorly draining soils, rapid drawdown or excessive groundwater seepage. See Chapter 2, *Site Assessment* for more information about subsurface entrainment. See Chapter 3, *Reach Assessment* and the screening matrices in Chapter 5, *Identify and Select Solutions* for more guidance on the applicability of subsurface drains based on the mechanism of failure and causes of streambank erosion.

Variations

The purpose of subsurface drains in slopes is to provide an efficient and effective way for water contained in the slope to drain. This, in turn, reduces soil-pore pressure and enhances slope stability. Any mechanism that serves this purpose can be considered a subsurface drain. Characteristics that make a particular internal drainage system suitable for use in streambanks include:

- ease of installation,
- resistance to clogging,
- availability of construction materials, and
- unlikelihood of acting as a failure plane and precipitating slope failure.

Low potential for becoming clogged is important for streambank drainage systems because of the high volume of water they must convey. Unlike drains in the typical hill slope setting, streambank drainage systems must perform under rapid drawdown conditions, which produce high rates of seepage flow in bank materials. Such high rates will tend to clog poorly designed drains quickly. Subsurface drains constructed of natural materials are desirable in situations where erosion may otherwise expose and carry away portions of the drain, such as when streambanks are designed to allow a degree of natural deformation.

It is important that subsurface drains not become a failure plane. Many of the commercially produced drainage materials are designed for placement against retaining walls and foundations. When these materials are placed within the unsupported soil of a streambank, they can act as a failure plane.

Gravel seams and sloped sheet drains slope back into the bank at an *angle*. These drains typically underlie the treatment that is applied to the bank face (e.g., stepped geocellular system or fabric encapsulated soil). They form a planar surface that separates the native bank material (or fill) from the surface bank treatment. In this application, they can double as filter material for rock-toe and riprap treatments (see the discussions in this chapter addressing the techniques, *Rock Toes* and *Riprap,* for additional information). Seepage enters the drain from the overlying bank face and the underlying native bank material and is transmitted downward into a collection drain or porous bank toe.

Chimney drains are vertical drains that typically feed into a collection drain at their base. Chimney drains can be constructed of natural granular, sheet drain or high-profile drain materials. Chimney drains function in a manner similar to gravel seams and sloped sheet drains. Used primarily in conjunction with building foundations and retaining walls, chimney drains are commonly installed directly against a supportive structure. In bank construction, chimney drains may be installed on the back side of supportive structures such as cribwalls.

Collection drains lie along the base of gravel seams, sloped sheet drains and chimney drains. They collect discharge from these overlying drains and discharge it into the adjacent stream or river. Collection drains can be constructed of natural granular materials, synthetic materials, perforated pipe or any combination of these materials. Often, gravel seams, sloped sheet drains and chimney drains connect directly to a bank toe constructed of stone or similar porous material. In this case, the bank toe acts as a collection drain.

Emergency

Subsurface drainage systems are generally not practical for emergency applications.

EFFECTS

Subsurface drains generally improve bank stability and can increase the integrity of structural bank-protection techniques. However, the necessity of major excavation for installation results in a significant impact to riparian and bank vegetation and roots. Furthermore, drains may result in dry soils along streambanks, jeopardizing the survival of moisture-dependent riparian plants.

DESIGN

Generally, subsurface drainage is worthy of consideration in cases where streambanks are steep or high, or where other factors are present that bring slope stability into question. In such cases, a geotechnical engineer should be employed to assess bank stability under all expected conditions and to assist in subsurface drain design. Consult geotechnical manuals or manufacturer specifications for design drawings.

Design Criteria

Subsurface drains should be designed to meet the following design criteria:

- the drain should have adequate capacity to rapidly dewater the streambank,
- the drain must not allow soil particles to clog the filter surface or core,
- the drain must not act as a failure plane within the bank (sheet drains and filter fabric may be more likely to do this than natural granular materials),
- the drain should extend high enough and low enough within the bank to intercept seepage from highly permeable layers in the bank soil profile (it should adequately drain all components of a bank-treatment system that require such drainage), and
- the drain system should discharge through the bank toe.

Most geotechnical design manuals include information on subsurface drainage-design. These manuals are also a good source for finding drawings and pictures of subsurface drainage systems. In addition, riprap-design methods generally include procedures for gravel-filter design that are also appropriate for gravel-seam design (refer to the discussion on *Riprap* in this chapter).

Gravel Seams

Methods for granular-filter design are included in most riprap design manuals (see discussion about the use of *Riprap* in this chapter). A typical gravel seam drain is eight to 12 inches thick and composed of gravel whose size has been selected to bar the entry of native soil particles. Occasionally, particularly if the native bank material is very fine-grained, a layered filter composed of progressively finer granular materials is required. Alternatively, geotextile filter fabric is sometimes used as an outer layer for gravel drains in fine-grained soils.

In most cases, if a gravel seam of evenly-graded gravel is installed at a 2:1 slope or flatter, it will not be prone to acting as a failure plane. Steeper seams and seams placed in a bank with an inherently unstable soil profile should be analyzed by a geotechnical engineer before installation is attempted.

Gravel is often used as a filter layer under riprap and articulated concrete blocks. When used in this capacity, the gravel also serves as a subsurface drain.

The outlet for a gravel seam is typically the bank toe (generally constructed of stone or similar porous material). Connectivity must be maintained between the gravel seam and the porous toe material to allow free flow of water. Alternatively, a collection drain can be used to receive seepage from the gravel seam and transmit it to the bank toe.

Sloped Sheet Drains

Manufactured sheet drains can be oriented such that they angle back into the bank like gravel seams. They have the potential of acting as a failure plane if installed too steeply or if bank materials are prone to sliding or rotational failure, so it is important that a geotechnical engineer be involved in the design of them.

Chimney Drains

Like sheet drains, chimney drains have the potential of acting as failure planes in streambanks. For supported banks, such as banks faced by cribwalls, chimney drains are typically installed directly behind the supporting structure. Under these conditions, structural design should consider the effects of chimney drains on the behavior of the bank soil retained behind the supporting structure.

Horizontal Collection Drains

Collection drains are linear structures oriented parallel to the bank face at the bank toe. Typically, the horizontal and vertical extent of collection drains within the bank cross section is not extensive. Thus, by themselves, collection drains hold less potential for acting as failure planes than do the other types of drains previously discussed.

Whether collection drains are constructed of gravel, perforated pipe, high profile drains or a combination of these materials, there are several general guidelines for their design. Like other types of drains, a collection drain must have adequate conveyance capacity to efficiently dispose of all collected water. Collection drains must also be designed so as not to clog with particles from the surrounding soil. Finally, collection drains must include a means of efficiently discharging collected water into the stream. This discharge is most easily accomplished by routing the collection drain into the back of a bank toe constructed of stone or similar porous material. Alternatively, collection drains can discharge into a stone-and-gravel filled sump at the toe of the bank. The sump design should recognize the dominant stream-sediment processes at the proposed site.

BIOLOGICAL CONSIDERATIONS

Mitigation Requirements for the Technique

Subsurface drains are often installed associated with a surface bank treatment, and the mitigation requirements depends mostly upon the mitigation requirements of the associated surface treatment. Refer to Chapter 4, *Considerations for a Solution* for further discussion of mitigation. Depending upon drain configuration, the inclusion of a drain in association with a surface bank treatment generally will not increase the impacts of the surface treatment appreciably. Significant, additional excavation may be required to accommodate a drain, in which case the impacts will typically be in the form of disturbance to riparian vegetation. In such instances, action such as replanting should be undertaken to mitigate for this disturbance. Refer to Chapter 4 and Matrix 3 in Chapter 5 for more detail on mitigation needs for this bank treatment.

Mitigation Benefits Provided by the Technique

There are no mitigation benefits provided by this technique, though it may reduce the amount of instream work.

RISK

In general, drains will decrease risk to property and infrastructure behind the banks by enhancing bank stability. However, an improperly designed or constructed drain may have the potential to serve as a plane for bank failure.

Risk to habitat will be dictated by the bank-protection technique constructed in association with the drains.

Drains may result in decreased water availability to riparian plant species.

Reliability/Uncertainty of Technique

If properly designed, subsurface drains can serve reliably for many years.

CONSTRUCTION CONSIDERATIONS

Disturbance of Vegetation

Subsurface drains require complete excavation for installation. Consequently there will be a significant impact to existing vegetation and roots. Removal or root disturbance of riparian trees and shrubs should be minimized on all bank-treatment projects, though complete removal of these plants should be anticipated and mitigated (see Appendix H, *Planting Considerations and Erosion-Control Fabrics*).

Materials Required

Typical subsurface drainage materials include natural, granular materials (such as gravel and sand) and manufactured soil-drainage products (such as sheet drains, high-profile drains, synthetic filter fabric and perforated pipe).

Natural, granular materials have the advantages of being locally available and relatively inexpensive, easy to install, aesthetically appealing and biologically inert if exposed by erosion. Additionally, they are not particularly prone to acting as a failure plane.

Sheet drains are composed of synthetic materials configured such that water is filtered by the outer layer of the drain and conveyed efficiently by the inner layer. Sheet drains are easy to install and can be oriented vertically within a supported bank (e.g., behind a log cribwall or similar supportive structure). Caution should be used when using sheet drains in unsupported banks as they may act as a failure plane.

High-profile drains are similar to sheet drains, but are narrower and flatter than sheet drains. High-profile drains are often used as collection drains at the base of sheet drains.

Synthetic filter fabric can be useful as a component of composite drains. For instance, crushed gravel is often wrapped in filter fabric to form subsurface drains. In this configuration the filter fabric prevents fine soil particles from entering the gravel, while the gravel provides a highly porous conduit for water to exit the bank.

Perforated pipe is also generally used as a component of composite drains. It is often laid in a trench and surrounded by gravel or sand. As water passes through the surrounding granular materials towards the pipe, fine soil particles are filtered out. The filtered water that enters the pipe is then efficiently conveyed out of the bank.

Timing Considerations

Because subsurface drains usually underlie a surface bank treatment, they are often the first component to be installed in bank treatments. Drains should be installed during low flow, when dewatering is possible, and when resident and anadromous fish are less likely to be impacted by construction activities. Dewatering allows for ease of installation and prevents siltation of the stream during construction. This can be accomplished with a coffer dam during low water.

Critical periods in salmonid life cycles such as spawning or migration should be avoided. Instream work windows vary among fish species and streams. Contact the Washington Department of Fish and Wildlife's Area Habitat Biologist for information on work windows (see Appendix B, *Washington Department of Fish and Wildlife Contact Information*). Further discussion of construction timing and dewatering can also be found in Appendix M, *Construction Considerations*.

Cost

The cost of subsurface drains will include the materials selected, excavation, labor and equipment needed. Costs will be influenced by availability, transport and site access. Costs tend to vary significantly from site to site due to the wide range of materials and approaches available. For the most part, prices also fluctuate greatly both geographically and over time. Prices for gravel filter drains have remained fairly stable, however, and typically range from $30 to $160 per cubic yard.

For further discussion of costs, refer to Appendix L, *Cost of Techniques*.

MAINTENANCE

Subsurface drains cannot be accessed once installed, nor can they be easily monitored, except by examining the banks in which they are installed. When pipe is used to construct drains, cleanouts should be conducted at all junctions and at intervals of 100 feet. Pipes should be cleaned twice per year and at least once soon after any high flows.

MONITORING

Subsurface drains cannot be reasonably monitored independent of their associated bank treatment. Normal monitoring protocol established for the associated bank treatment should be sufficient for the subsurface drains. The effectiveness of subsurface drains in dewatering the bank can, however, be monitored indirectly by examining for signs of seepage at the bank surface or slumping/sliding of the bank surface. Refer to the monitoring discussion for the associated bank protection techniques described in this chapter and to Appendix J, *Monitoring*, for further details on monitoring protocol.

Floodplain Roughness
Avulsion-Prevention Techniques

DESCRIPTION

Floodplain roughness is a preventative technique used to decrease overbank flow velocity and related shear stress when there is a potential for a channel avulsion or chute cutoff to form. An increase in roughness is affected by the presence of live trees and shrubs, and large woody debris in the floodplain. This technique is also referred to as floodplain tree/large woody debris rows, live siltation fences, brush traverses, brush rows and live brush sills.[1] *Figure 6-41* shows various examples of natural floodplain roughness.

APPLICATION

Floodplain roughness elements are used in areas where the floodplain is either newly constructed or where land-management practices have left little natural roughness, leaving the stream susceptible to avulsion. A channel may also be prone to an avulsion or chute cutoff if the basin hydrology is flashy (rapid changes in discharge levels and water-surface elevation associated with storm events) or if the channel is aggrading, resulting in frequent overbank flow events. Refer to Chapter 2, *Site Assessment* and Chapter 3, *Reach Assessment* for further discussion of site-related and reach-related causes of an avulsion or chute cutoff. Typical implementation of floodplain roughness includes placing large woody debris perpendicular to the predicted overbank flow direction at the locations where an avulsion or cutoff is likely to form. If shear stresses are high during flood flows, large woody debris can be anchored to the floodplain. Live trees or dense rows of live cuttings may also be planted in rows roughly perpendicular to the channel.[1]

Floodplain-roughness approaches are generally appropriate when there is potential for an avulsion or chute-cutoff to occur. Refer to matrices in Chapter 5, *Identify and Select Solutions* for assistance regarding the proper selection and application of the most suitable technique for the circumstances in question. Floodplain roughness elements may be inappropriate in floodplains naturally devoid of woody vegetation (e.g., low-gradient, meadow-stream systems). In such instances, the risk and consequences of an avulsion forming are generally low.

Emergency

Floodplain-roughness elements are used as a preventative measure and have little utility in an emergency situation where the channel is in imminent danger of forming an avulsion or chute cutoff. However, it may be possible to install roughness structures (e.g., ecology blocks, large woody material) across the floodplain during an emergency overbank situation where flows are concentrated, with active headcutting.

EFFECTS

Floodplain roughness elements slow overland flow velocity during flood events by increasing roughness which slows floodplain flow velocity and dissipates energy. The net result is that the stream is less likely to abandon its current channel and create a new one.

Floodplain roughness may also increase depth of flow in the floodplain by reducing velocity during overbank flow events. In situations with strict floodplain- and flood-management regulations, the potential effect of increased flow depth should be evaluated with respect to allowable increases in flood-level flow elevations.

DESIGN

Flow velocity, depth and shear stress in the floodplain from overbank flows are modeled using hydraulic models, such as HEC-RAS.[2] The results from these models are then used to design a treatment that reduces floodplain shear stress and the risk of an avulsion or chute cutoff. Refer to the Appendix E, *Hydraulics* for further discussion of calculating shear. A conceptual design drawing is shown in *Figure 6-42*.

Large woody debris or vegetative roughness elements are placed on the floodplain approximately perpendicular to the down-valley slope on either side of vulnerable locations, such as at tight bends.[1] A combination of riparian plantings, live brush rows and large woody debris can be used individually or in combination. Native riparian plantings are densely planted in a random pattern on the floodplain. It is recommended that various configurations of live cuttings be oriented into multiple rows (live brush rows).[1] Multistemmed shrubs are preferable over single-stemmed trees, since they tend to disperse flood flows and encourage sediment deposition. The use of live cuttings is preferable over container or bare-root plants since they can be planted deep enough to reach the water table and are less prone to washout during flood flows. For guidance on planting, see the discussion in this chapter addressing the technique, *Woody Plantings*, and to Appendix H, *Planting and Erosion-Control Fabrics*.

Large woody debris may need to be anchored to the floodplain if high shear stresses are anticipated during design flood flows (see Appendix I, *Anchoring and Placement of Large Woody Debris* for additional information). Large woody debris with intact branches is preferable, since the branches provide greater roughness than a bare tree trunk does. If this is not available, an alternative is to cable multiple bare logs together into a matrix configuration to simulate a tree with intact branches. The design should not result in substantial reduction in floodplain flow conveyance.

BIOLOGICAL CONSIDERATIONS

Mitigation Requirements for the Technique

No mitigation is required for implementing this technique. Refer to Chapter 4, *Considerations for a Solution* and Matrix 3 in Chapter 5 for additional guidance concerning mitigation.

Mitigation Benefits Provided by the Technique

Adding large woody debris or live plants to the floodplain, in most instances, increases biologic diversity for terrestrial plants and animals and roughness and complexity to the floodplain.

This technique provides protection for the maintenance and integrity of the floodplain or other elements at risk. If the risk of avulsion that is being managed is created or exacerbated by man-made conditions, there may be a biological benefit to controlling the induced avulsion. Conditions that might warrant protection from an avulsion include increased sediment or peak flood events specifically due to human land-use activities.

RISK

Habitat

There is little risk to either aquatic or terrestrial habitat from this technique.

Infrastructure

This technique may decrease the risk to infrastructure on the banks and in the floodplain.

Reliability/Uncertainty of Technique

Reliability of the technique is based upon being able to predict where an avulsion might occur and placing roughness elements in that location. Roughness elements can inadvertently concentrate flows in other areas of the floodplain, thereby increasing the potential for an avulsion or chute cutoff to occur in those areas. In instances where live vegetation is planted for the purpose of roughness, success will depend on plant survival.

CONSTRUCTION CONSIDERATIONS

Materials Required

Appropriate woody-debris materials include rootwads, logs or whole trees. Likely candidates for live trees and shrubs include alder, cottonwood and willow. The application of erosion-control fabric that is both biodegradable and erodable on a constructed floodplain surface may be appropriate to provide protection while vegetation becomes established. During emergency situations, ecology blocks can be applied as a temporary measure.

Timing Considerations

Placement of woody debris is desirable before periods when higher flows are expected. Planting of live trees and shrubs may occur either in early spring or late fall to facilitate their survival. For additional information, refer to the discussion in this chapter addressing *Woody Plantings* and to Appendix H). Floodplain roughness should not require working the active stream channel and so is not affected by instream construction windows.

Cost

The cost of installing floodplain roughness elements can be minimal if locally available large woody debris is used. Costs increase substantially when using live plantings and varies according to the maturity of the plants. Seedling plantings can be acquired and planted relatively inexpensively, but they do not provide immediate protection or benefit. Larger, potted, plant stock is more expensive than seed, and the labor costs are higher to install. But these more mature plants will provide benefits sooner. For further discussion of materials costs, particularly for vegetation, refer to Appendix L, *Cost of Techniques*.

MAINTENANCE

Roughness elements consisting of large woody debris do not require regular maintenance. However, maintenance may be needed following large flood events. For instance, woody debris may need to be re-anchored or replaced. Live plantings may require considerable maintenance and possibly irrigation during the first year. Additional live trees and shrubs may be needed to replace trees lost to mortality.

In the event that monitoring indicates development of scour or a floodplain channel following an overbank flow, maintenance of existing treatment, or application of other avulsion-prevention techniques may be appropriate. Refer to the discussions in this chapter addressing *Floodplain Flow Spreader and Floodplain Grade Control* for additional information regarding other avulsion- and chute-cutoff-prevention techniques.

MONITORING

All roughness elements installed should be mapped at the time of installation, and photo points should be established that are clearly identified on base maps. Monitoring will be qualitative for the most part. It should consist of visual observation and photo documentation from established photo points. Any roughness elements lost during overbank flow events can be indicated on base maps. Monitoring should be conducted following all overbank flows to observe any scour development or channel development on the floodplain in addition to any debris deposited by large flood events. Additionally, monitoring should include documentation of plant growth on the floodplain. Refer to Appendix J *Monitoring* for additional guidance on monitoring-plan development and monitoring methods.

REFERENCES

1 Sheicthl, H. M. and R. Stern. 1994. Water Bioengineering Techniques for Watercourse, Bank and Shoreline Protection. Blackwell Sciences, London, UK. 189 pp.

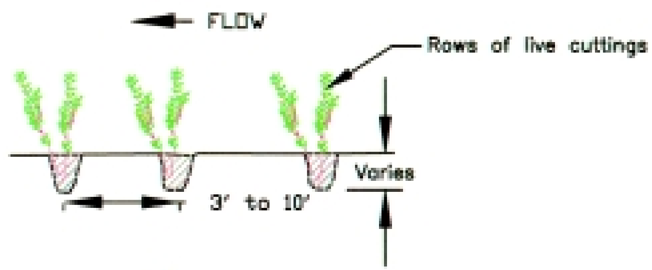
2 U. S. Army Corps of Engineers. 1997. HEC-RAS, River Analysis System, Version 2.0. Hydrologic Engineering Center, Davis, CA.

a. Floodplain Roughness using large woody debris. Clearbranch Creek, OR.
Source: Inter-Fluve, Inc.

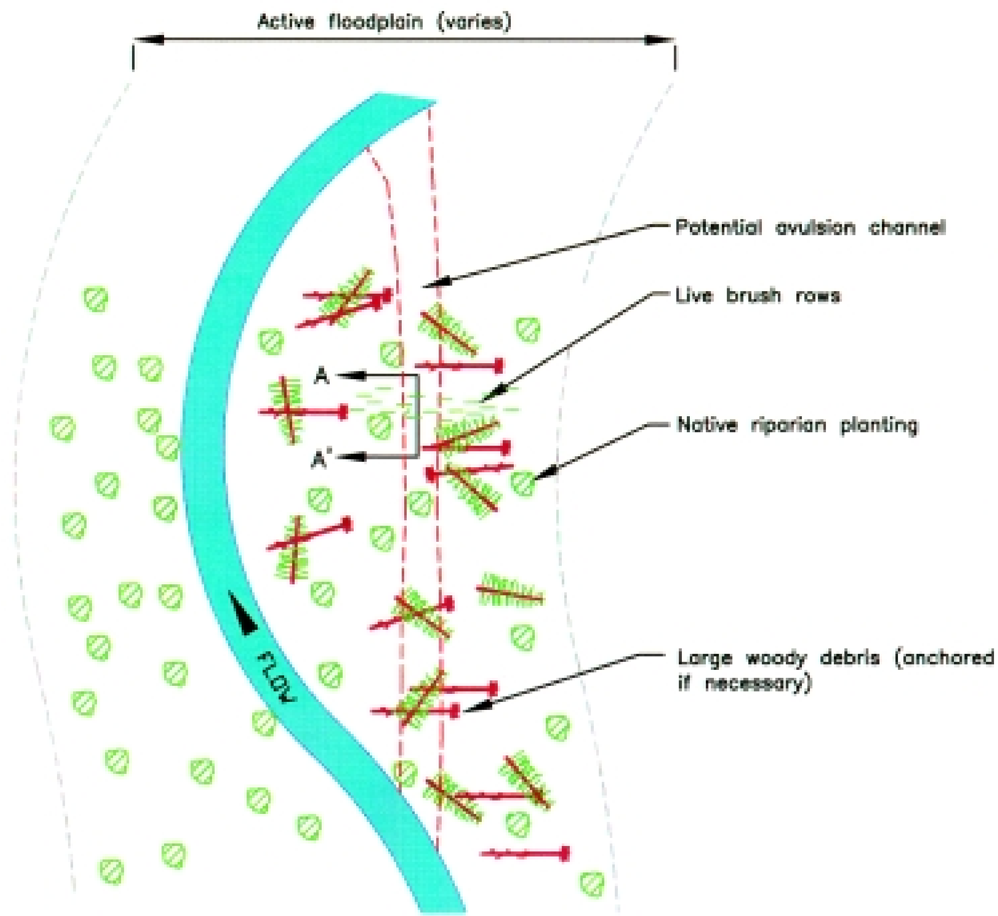
b. Floodplain Roughness. Woody plantings planted on floodplain for roughness. Salmon Creek, Tributary to Columbia River.
Source: Inter-Fluve, Inc.

c. Floodplain Roughness. Tree rows planted in floodplain for roughness. 1997.

Figure 6-41. Various examples of floodplain roughness.



Section A–A': Live brush rows



Notes:

1. Riparian plantings, live brush rows and LWD can be used individually or in combination to increase roughness and sediment deposition.
2. Flexible, multi–stemmed shrubs may be better choices on floodplain plantings compared to single–stemmed trees; they tend to better disperse flood flows, and encourage sediment deposition.
3. In riparian plantings and live brush rows the use of live cuttings may be better than containers or bare–root plants because they can be planted deep enough to reach water tables, are well suited to course floodplain soils, and are less prone to wash–out during flood flows.
4. LWD may need to be anchored based on design flood flows.

NOT TO SCALE

FIGURE 6–42	FLOODPLAIN ROUGHNESS CONCEPTUAL DESIGN	INTEGRATED STREAMBANK PROTECTION GUIDELINES www.wa.gov/wdfw/hab/ahg/strmbank.htm

Floodplain Grade Control

Avulsion-Prevention Techniques

DESCRIPTION

Floodplain grade-control structures prevent avulsion or chute cutoff. They are made of erosion-resistant material, such as large rock or logs, and they work on the subsurface level of the floodplain to prevent overland flow from forming a new channel where public safety or property may be threatened. These structures are placed in the floodplain, perpendicular to the down-valley direction, to prevent flood flow from scouring and headcutting a new channel into the floodplain (see *Figure 6-43* for an example of headcutting).

APPLICATION

Typical Application

Floodplain grade-control structures are typically used where there is potential for an avulsion or chute cutoff to develop. Floodplain grade control is used in areas where the floodplain is susceptible to an avulsion of a chute cutoff, either because it is newly constructed or it has little natural roughness due to land management practices. A channel may also be prone to an avulsion or chute cutoff if the channel is aggrading or if the basin hydrology is flashy (experiences rapid changes in flow level). Refer to Chapter 2, *Site Assessment* and Chapter 3, *Reach Assessment* for further discussion of site and reach based causes and mechanisms of an avulsion chute cutoff. The screening matrices in Chapter 5, *Identify and Select Solutions* contain additional guidance on the applicability of floodplain grade controls based on site- and reach-based mechanisms and causes of failure.

Variations

Floodplain grade-control structures can be used in conjunction with floodplain-roughness elements such as large woody debris and live trees to promote or direct flow within the channel and channel margin (see the section in this chapter that addresses *Floodplain Roughness* for more information). These floodplain-roughness elements are the "surface" component of headcut or avulsion preventionn. Floodplain grade-control structures are the "subsurface" component of headcut or avulsion prevention.

It may be appropriate to add woody or herbaceous plantings to floodplain grade controls to improve the biological value and aesthetics of these structures. See the technique discussions in this chapter addressing *Woody Plantings* and Appendix H, *Planting Considerations and Erosion-Control Fabrics* for more information.

Emergency

Grade-control structures can be installed following the onset of headcut development after flood water have receded. Once a new channel is formed, the channel adapts to fit the newly avulsed location and any attempt to direct the stream back into the original channel would be a channel-realignment project rather than an avulsion-prevention measure.

EFFECTS

Grade-control structures prevent headcutting by resisting the erosive forces of flood flows impinging on the floodplain. This resistance does not allow overbank flood flows to cut a new channel through the floodplain. While this may be desirable in terms of protecting property, the opportunity for new habitat to develop due to channel migration and side-channel development will be lost. Conceptual design drawings are shown in *Figure 6-44* and *Figure 6-45.*

DESIGN

The use of grade-control structures to prevent avulsion and chute cutoff is an untested method, so any design guidance that is currently available is only conceptual and preliminary. Once the method has been applied and tested, additional design guidance will become more refined.

It is possible to determine overbank (floodplain) flow velocity, depth and shear using backwater hydraulics models such as HEC-RAS or at-a-station modeling. Refer to Appendix E, *Hydraulics* for further discussion on how to calculate shear. Incipient-motion analysis can be used to determine the rock size needed to resist headcutting and preserve the integrity of the floodplain.

Once the median rock size (D_{50}) needed to resist entrainment is known, a gradation can be developed to determine the D_{15}, D_{90} and the relative amounts of all three sizes to be used in the construction of the grade-control structure. Federal Highway Administration and U.S. Army Corps of Engineers publications[1,2] provide guidance for determining gradations using standard riprap gradation methods. Rock should be placed to a depth of 1 to 1.5 times the expected scour depth, according to best engineering judgement. The grade-control structure should be positioned roughly perpendicular to the down-valley direction and span the area where erosive shear stresses are expected or predicted by hydraulic modeling.

Grade-control structures are installed with their top elevation flush with the channel-bed elevation or the swale elevation in which they are installed. They may be covered or left uncovered. The structure should extend across the entire channel or swale and be tied into the margins of the channel to prevent scour at the ends of the structure. Tie-in portions should be sloped upward (in an across-valley direction) at an angle of at least 5:1 or to match the existing ground contours to prevent flows from eroding around the margins of the structure.

If floodplain shear stresses are moderate, logs can be used in the floodplain as grade-control structures. The correct size for logs to be used can be determined by a summation of forces analysis using an appropriate density value for the wood used. Logs should be placed to a depth twice the log diameter and securely anchored. See Appendix I, *Anchoring and Placement of Large Woody Debris* for more information about anchoring large woody debris.

To any extent possible, vegetation should be incorporated into grade controls. Vegetation within a grade-control structure may act as a flow spreader to further reduce the avulsion or chute-cutoff risk (see the discussion in this chapter addressing the technique, *Floodplain Flow Spreaders,* for additional information). This may require the use of erosion-control fabric to hold soils in place while vegetation becomes established. Refer to Appendix H for further information on both planting and appropriate erosion-control materials for vegetated grade controls.

Location

In instances where a headcut exists, the grade control should be located at the head of the headcut, with consideration to scour at the toe of the structure. Where a headcut does not exist, but is likely to develop, a grade-control structure should be placed near the anticipated origin of the headcut. This will generally be near the downstream end of an existing overflow channel or swale. To avoid impacts to the downstream channel and the riparian area that may contribute to habitat and/or avulsion protection, structures should be place upstream from the point where the headcut channel will re-enter the main channel.

A series of grade-control structures can be built in the alignment of an avulsion or chute cutoff if the total head differential is greater than what can be dissipated successfully by a single structure.

BIOLOGICAL CONSIDERATIONS

Mitigation Requirements for the Technique

Grade-control structures interfere with natural stream processes by halting natural avulsion or chute-cutoff processes that may occur during flood events. Consequently, mitigation for lost opportunity will be required. Refer to Chapter 4, *Considerations for a Solution* and Matrix 3 in Chapter 5 for additional guidance concerning mitigation.

Mitigation Benefits Provided by the Technique

No immediate mitigation benefit is realized from installing grade-control structures. This technique simply provides protection for the maintenance and integrity of the floodplain or other elements at risk. If the risk of avulsion or chute cutoff is created or exacerbated by man-made conditions, there may be a biological benefit to controlling the induced avulsion. Conditions that might warrant protection from an avulsion include increased sediment or peak flood events specifically caused by human land-use activities.

RISK

Habitat

There is little risk to existing aquatic or terrestrial habitat from this technique if properly installed. However, there may be significant lost opportunity for riparian and off-channel aquatic habitat associated with preventing channel avulsion.

Infrastructure

This technique may decrease the risk to infrastructure on the banks and in the floodplain.

Reliability/Uncertainty of Technique

Reliability of the technique depends on being able to predict where a headcut might occur. The greatest uncertainty in the structural success of the technique is in calculating the flow and head differential across the structure and, therefore, its scour potential.

CONSTRUCTION CONSIDERATIONS

Materials Required

Required materials include graded rock or logs, or other material used to form the structure. Angular rock with a minimum density of 150 lbs/ft^3 is desirable for the construction of floodplain grade control structures. For further description of materials for grade controls, refer to the technique discussion in this chapter addressing *Drop Structures*.

Timing Considerations

Construction of floodplain grade-control structures is best timed after runoff, but early in the growing season so that a full growing season is provided for the vegetation overlying the structure prior to subsequent overbank flows. Floodplain grade-control drop structures should not require work in the active strean channel and so are not affected by instream construction windows.

Cost

The primary cost of installing grade-control structures is the purchase of graded rock, logs or other material used to form the structures and the equipment required to install the materials, including that used for excavation and for hauling and placement. For further discussion of costs of materials, refer to Appendix L, *Cost of Techniques*.

MAINTENANCE

Grade-control structures do not require regular maintenance. However, maintenance may be needed in the aftermath of a large flood event. Maintenance may involve repositioning and/or addition of materials following flood events. In the event that materials are added to these structures, some level of maintenance may be required.

MONITORING

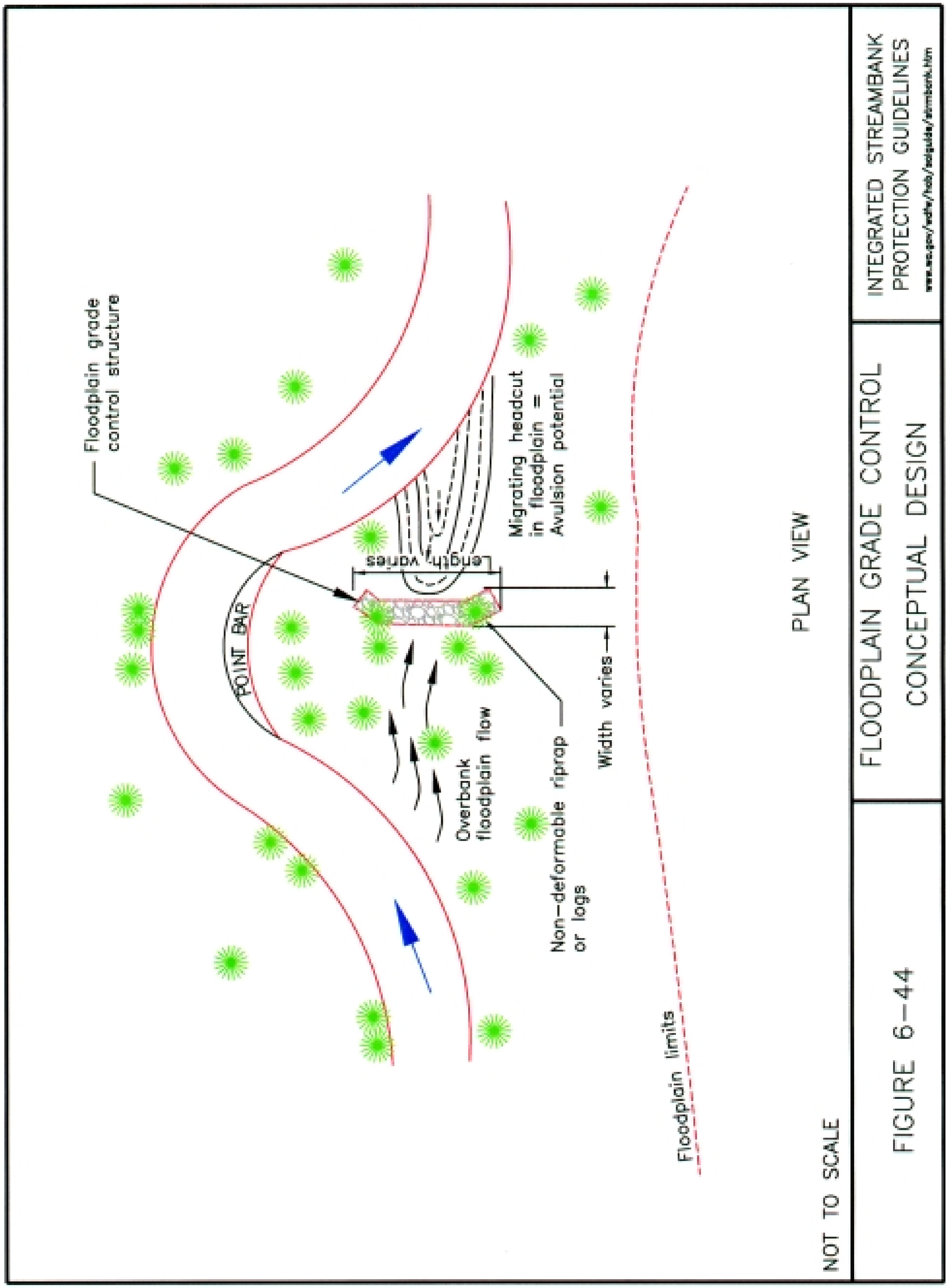
Monitoring of floodplain grade control structures should be conducted following any overbank flows to determine whether headcuts have developed and, if they have developed, whether they are moving toward the grade-control structure or have reached it. Visual inspection is sufficient to determine success and maintenance requirements. Any plantings should also include monitoring. Refer to Appendix J, *Monitoring* for additional guidance on monitoring-plan development and monitoring methods.

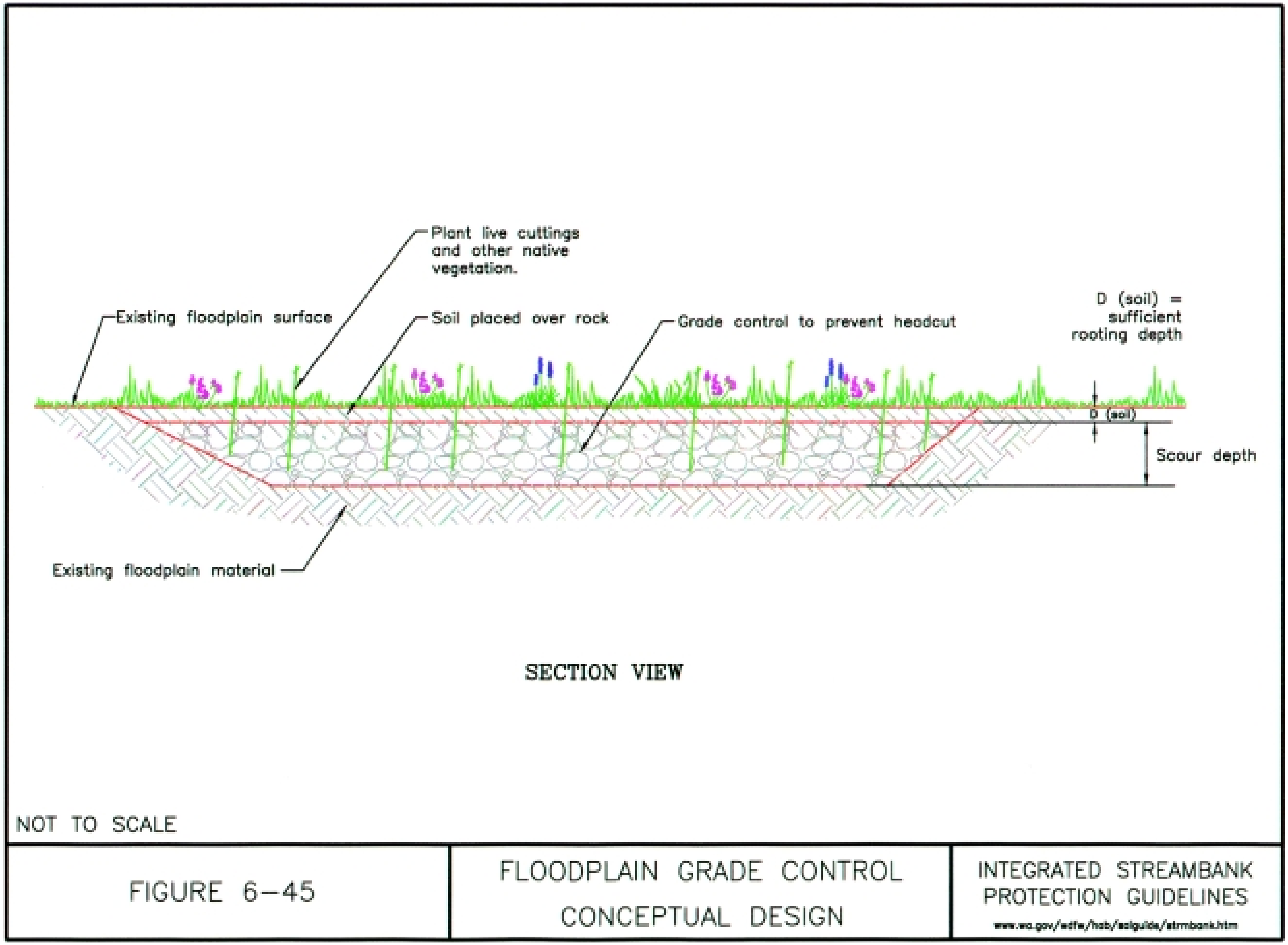
REFERENCES

1 U. S. Department of Transportation, Federal Highway Administration. 1989. Design of Riprap Revetment. Hydraulic Engineering Circular No. 11.

2 U. S. Army Corps of Engineers. 1994. Hydraulic Design of Flood Control Channels. Engineer Manual 1110-2-1601.

Figure 6-43. Headcut in floodplain. Site of future floodplain grade control structure at nickpoint of headcut. Teanaway River. 1996.


Floodplain grade control structure
Migrating headcut in floodplain = Avulsion potential
Length varies
POINT BAR
Overbank floodplain flow
Non-deformable riprap or logs
Width varies
Floodplain limits
PLAN VIEW
NOT TO SCALE
FIGURE 6-44
FLOODPLAIN GRADE CONTROL
CONCEPTUAL DESIGN
INTEGRATED STREAMBANK PROTECTION GUIDELINES



Plant live cuttings and other native vegetation.
Existing floodplain surface
Soil placed over rock
Grade control to prevent headcut
D (soil) = sufficient rooting depth
D (soil)
Scour depth
Existing floodplain material
SECTION VIEW
NOT TO SCALE
FIGURE 6-45
FLOODPLAIN GRADE CONTROL CONCEPTUAL DESIGN
INTEGRATED STREAMBANK PROTECTION GUIDELINES
www.wa.gov/wdfw/hab/ahg/strmbank.htm

Floodplain Flow Spreaders

Avulsion-Prevention Techniques

DESCRIPTION

Floodplain flow spreaders are designed to spread overbank flood flow across the floodplain. By eliminating concentrations of flow and high velocities in the floodplain, the potential for an avulsion or chute-cutoff is reduced. The intent of flow spreaders is to restore the natural roughness of a floodplain that has been removed by land clearing and grading.

Flow spreaders can consist of a row or several rows of planted trees. The spreading of flow is done by the roughness of the vegetation and by an accumulation of debris that may be placed against the trees, or it may come from the floodplain or from the channel and be delivered by a flood. The debris will collect where most of the water moves. As it collects, the flow is shunted to other portions of the flow spreader. Flow spreaders can also be nondeformable and constructed of compacted soil or rock (and be used in combination with planted trees, if suitable). Such flow spreaders are designed to remain stable during high flows. *Figure 6-46* shows various examples of natural and constructed floodplain flow spreaders.

APPLICATION

Typical Application

A floodplain flow spreader is used to prevent an avulsion or chute cutoff from occurring. The spreader evenly distributes overbank flows across the floodplain, preventing flood flows from concentrating and scouring a new channel in the floodplain. Floodplain flow spreaders are used in areas where the floodplain is susceptible to an avulsion or chute cutoff, either because it is newly constructed or it has little natural roughness due to land-management practices. A channel may also be prone to an avulsion if the basin hydrology is flashy (experiences rapid changes in flow level) or if the channel is aggrading, resulting in frequent overbank flow. Refer to Chapter 2, *Site Assessment* and Chapter 3, *Reach Assessment* for further discussion of site-based and reach-based causes and the consequences of an avulsion or chute cutoff. Floodplain flow spreaders are typically constructed as low berms across the floodplain, perpendicular to the flood flow direction. Tree rows and piles of large woody debris are also natural floodplain flow spreaders. Flow spreaders can be notched to allow flow passage between adjacent, elevated segments.

Flow spreaders are also used in combination with other bank-protection techniques, particularly toe erosion and channel migration techniques where there is a potential for a chute cutoff. For more information about chute cutoffs, refer to Chapters 2 and 3.

Floodplain flow spreaders are appropriate for areas with moderate avulsion or chute-cutoff potential. Refer to the matrices in Chapter 5, *Identify and Select Solutions* matrices further detail on situations where they are suitable for use.

Variations

A floodplain flow spreader may be used in conjunction with a floodplain grade-control structure and floodplain-roughness elements to provide further protection against avulsion or chute-cutoff development. The grade-control structure can be considered the subsurface component of the flow spreader. Flow spreaders may be a row of trees or they may be nondeformable and constructed of rock large enough to be immobile under a specified range of flows. They may also be deformable and constructed of wood or composite vegetation-based materials.

Emergency

A floodplain flow spreader is preventive by nature and not particularly applicable in emergency circumstances. It's difficult, overly time-consuming and impractical to build them during flow events, and they are unlikely to significantly reduce an avulsion or chute cutoff that has already begun.

EFFECTS

A floodplain flow spreader distributes the erosive forces of flood flows over the floodplain, thereby reducing the potential for an avulsion or chute cutoff. Flow spreaders impact the development of off-channel and side-channel habitat. Consequently, evolution of these habitats may be reduced or lost.

DESIGN

Currently, design guidelines are conceptual and preliminary but will become more defined as the technique is tested under a variety of situations. A conceptual design drawing is shown in *Figure 6-47*.

The critical design parameter of a floodplain flow spreader is the base elevation of the structure and depth of flow on the floodplain at the flood event of interest. The top of the spreader should be at or near the flood-event elevation, with allowances for increased stage due to backwatering caused by the spreader itself. Flow spreaders constructed with fill material must not act as levees to change the rate or location of flow from the main channel entering the floodplain or flood channels. To ensure even distribution of water across the width of the floodplain, the elevation of the top of the spreader must be uniform across its length (cross-valley direction). It is important to note that the spreader will only diffuse flows at the location of the structure. Once overbank flow has passed the spreader, the flow will again follow the existing flow paths. For this reason, a series of spreaders may be necessary to effectively distribute flows within the specified length of a reach.

The width (down-valley dimension) of the structure should be equal to (at a minimum) the depth of installation (predicted scour). If scour depth cannot be predicted, the width of the structure should be twice the diameter of the largest rock gradation. In design and construction, the potential for scour resulting from flow dropping over the structure must be addressed. In such instances, scour should be calculated, and rock or other armor material that is adequately sized should be installed to a sufficient depth or anchored in place to protect against scour that could jeopardize the structure. For further discussion of calculating scour, refer to Appendix E, *Hydraulics*. Additionally, further design guidance is provided in this chapter under *Floodplain Grade Control*.

Flow spreaders have been built in agricultural fields with a low enough elevation and profile that farming activities are not affected.

Flow spreaders should be tied in to higher ground to prevent water from flowing around the spreader and scouring at the margins of the spreader. Tie-in design will be site specific.

Flow spreaders can be constructed from live trees, rock, soil, wood or other hard material. Alternatives include vegetated soil berms, wooden sills, or piles of large woody debris. Vegetated soil berms may serve the dual purpose of providing floodplain roughness as well. Soil berms will require erosion protection in the form of fabric to hold soils in place while vegetation becomes established. Refer to Appendix H, *Planting Considerations and Erosion-Control Fabrics* for further information on both planting and appropriate erosion-control materials for vegetated and soil berms.

While the spreader may be constructed of rock, it will be difficult to achieve uniform elevation across its length with larger rock. Rock must not be so small that it is subject to entrainment due to tractive forces at the design flood event. Rock should be placed in a stable configuration and keyed in below the floodplain surface to the depth of potential scour. Graded rock will allow interlocking of individual stones and should be sized such that the D_{50} is immobile at design flows.

BIOLOGICAL CONSIDERATIONS

Mitigation Requirements for the Technique

When this technique is used with a vegetative design, it usually restores natural streams and floodplains by returning roughness and complexity to the floodplain. Refer to Chapter 4, *Considerations for a Solution* and Matrix 3 in Chapter 5 for additional guidance concerning mitigation.

Floodplain flow spreaders made of fill material may reduce the potential and function of off-channel habitats associated with flood overflow swales. Concentrated flows in the floodplain often maintain side channels by scouring, cleaning and sorting bed material within them. Such lost-opportunity impacts must be mitigated.

Mitigation Benefits Provided by the Technique

This technique provides protection for the maintenance and integrity of the floodplain or other elements at risk. If the risk of an avulsion or chute cutoff that is being managed is created or exacerbated by man-made conditions, there may be a biological benefit to controlling the induced avulsion or chute cutoff. Conditions that might warrant protection from an avulsion or chute cutoff include increased sediment or peak flood events specifically due to human land-use activities.

RISK

Infrastructure

This technique may decrease the risk to infrastructure on the banks and in the floodplain. A flow spreader may increase the depth of flow in the floodplain during a given flood event.

Reliability/Uncertainty of Technique

Reliability of the technique depends on the accurate prediction of where a headcut might occur, correct placement of a floodplain flow spreader to prevent headcutting and the time it takes for development of vegetative flow spreaders to be functional.

CONSTRUCTION CONSIDERATIONS

Materials Required

Flow spreaders can be constructed from woody vegetation, rock, compacted soil, large woody debris or other hard materials. Where rock is used, angular rock with a minimum density of 150 lbs/ft^3 is desirable. Compacted soil berms will require erosion-control fabric (refer to Appendix H) to hold soil in place until vegetation becomes established. Large woody debris must be anchored or buried such that it does not become mobilized. Refer to Appendix I, *Anchoring and Placement of Large Woody Debris* for further information.

Timing Considerations

Construction of a floodplain flow spreader is best timed after moderate, overbank-flow events when there is clear evidence of the route the overbank flow will take. Floodplain flow spreaders should not require work in the active stream channel and so are not affected by instream construction windows.

Cost

The primary cost of building a vegetative floodplain flow spreader is in the rooted plantings required. As with many vegetative techniques, the sooner the protection needs to take hold, the larger the plantings should be and, therefore, the greater the cost. The primary cost of building a flow spreader of fill material lies in the purchase and transport of materials to the site. Equipment costs may also be significant. For instance, an excavator may be needed to install the material from a central stockpile, or a loader may be needed to place material throughout the floodplain. Refer to further discussion of costs of materials, equipment and other construction components in Appendix L, *Cost of Techniques*.

MAINTENANCE

Floodplain flow spreaders do not require regular maintenance. However, maintenance may be needed following a large flood event if parts of the spreader is washed away or if irregularities in the elevation across the spreader develop. Vegetative flow spreaders may have to be replaced eventually when trees are so large they no longer trap debris to spread the flow.

MONITORING

Flow spreaders should be monitored following all overbank-flow events to determine effectiveness and need for repair or maintenance. Development of new channels downstream of the spreader may indicate the need for additional spreaders. Flow spreaders should be mapped at the time of installation, and photo points should be established and clearly identified on base maps. Monitoring should consist of visual observation and photo documentation from established photo points and will be largely qualitative. Any flow spreader materials lost during overbank flow events can be indicated on base maps and replaced or repaired as necessary. Monitoring should be conducted following all overbank flows to observe any scour development or channel development on the floodplain in addition to any debris deposited by large flood events. Refer to Appendix J, *Monitoring* for additional guidance on monitoring-plan development and monitoring methods.

a. Natural Floodplain Flow Spreader. Note debris accumulation in floodplain. Skykomish River.

b. Small earthen berm spreads flow across floodplain. Nooksack River.

Figure 6-46. Examples of natural and constructed floodplain flow spreaders.

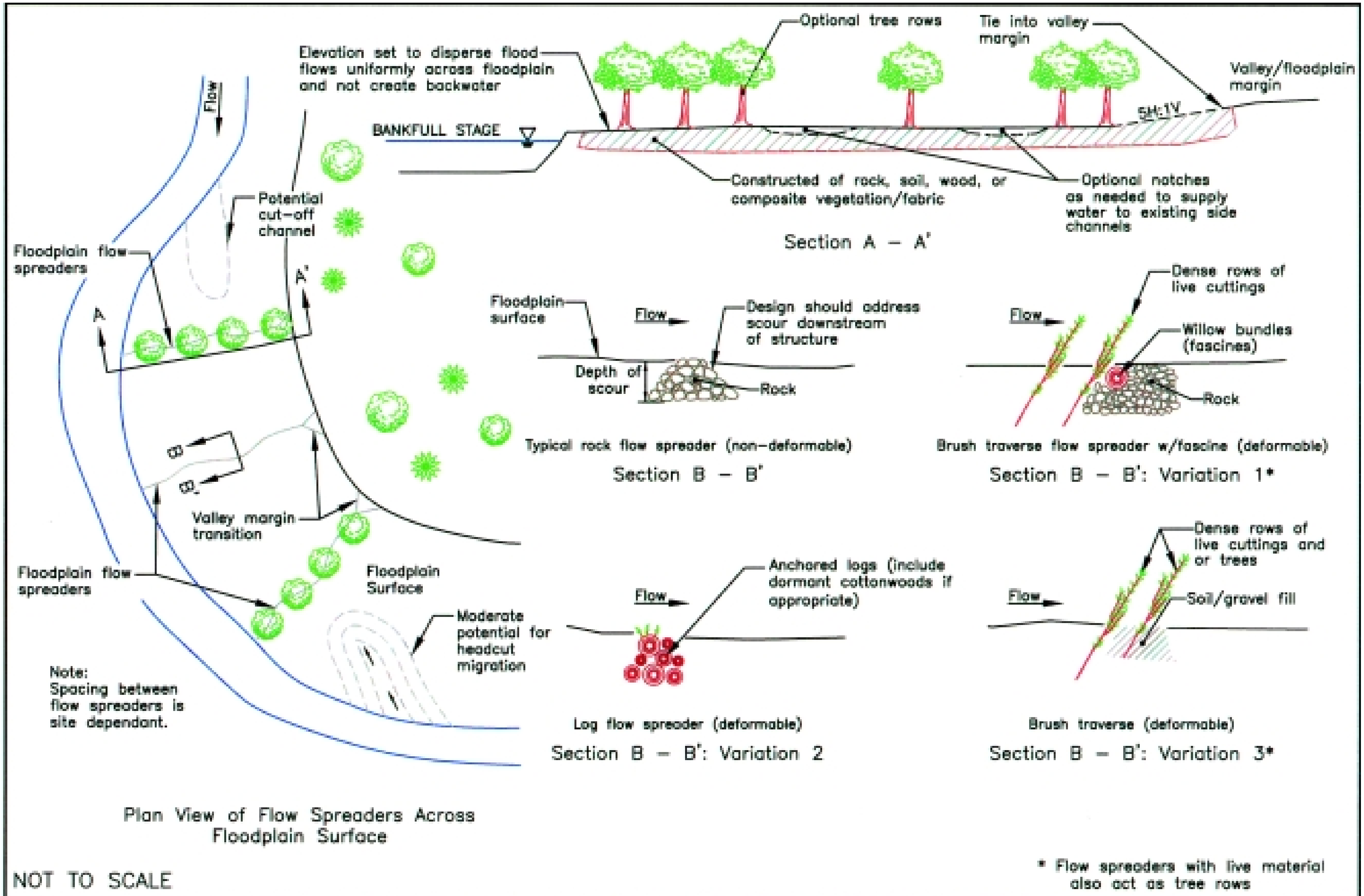


FIGURE 6–47

FLOODPLAIN FLOW SPREADER CONCEPTUAL DESIGN

INTEGRATED STREAMBANK PROTECTION GUIDELINES
www.wa.gov/wdfw/hab/ahg/strmbank.htm

Channel Modifications

Other Techniques

The following technique was developed for the Integrated Streambank Protection Guideline. Its focus is on streambank protection. While similarly titled techniques may appear in other Aquatic Habitat Guidelines, their contents may differ from the text presented here.

DESCRIPTION

Channel modification is the alteration of channel profile, planform, pattern, cross section, bed elevation and/or channel location of a stream segment or an entire reach. Channel modifications can be used separately or in combination to restore bank stability and to reduce bank erosion. Each of these modification techniques may specifically affect the local slope, length, sinuosity and dimensions of the channel, as well as alter basic channel processes related to sediment transport. While these techniques are not generally applied for the purpose of bank protection, channel-modification techniques are very useful for treating the underlying causes of bank erosion and for preventing future problems. They should, therefore, be considered as a potential solution where there are chronic or systemic bank-erosion problems present. *Figure 6-48* shows various applications of channel modifications.

The goal of channel modification is to restore or create an equilibrium (stable) condition in the stream reach (see Chapter 3, *Reach Assessment* for definition and discussion of channel equilibrium). A channel in equilibrium is one that has adjusted to the physiographic conditions (e.g., climate, geology, discharge, sediment supply) of its watershed. Keep in mind that throughout this document the terms "stable channel" and "equilibrium channel" refer to the geomorphic definitions described in Chapter 3 and do not necessarily mean a channel without erosion. A channel in equilibrium may still naturally erode as the channel migrates across the floodplain.

A channel in equilibrium can become unstable following some human or natural disturbance such as changes in hydrology or sediment loads, extreme hydrologic events or construction of channel confinements. Bank-protection and stream-restoration plans strive to attain or restore the channel to a state of equilibrium, based on the current and future hydrology and sediment supply of the stream.

Because all channel-modification techniques result in changes to channel process, a thorough understanding of fluvial geomorphology is an essential component of developing channel modification projects. Refer to Appendix F, *Fluvial Geomorphology* for further discussion of channel planform and profile, pattern, cross section and channel equilibrium.

APPLICATION

Channel-modification techniques can be used at a site to alleviate bank-erosion problems or to facilitate mitigation. They can also be used on a reach level to address geomorphic disequilibrium, thereby reducing risks of bank erosion. Common applications for channel modification include restoring a previously straightened stream reach to its historic channel planform and profile, or restoring an unnaturally braided channel to its natural, single-channel pattern. Other objectives of channel modification include:

- to increase habitat value and diversity,
- to dissipate excess stream energy, and
- to modify sediment-transport capability in either the project reach or downstream.[1]

For example, bank and channel stability may be achieved in a degrading channel system by modifying the channel to decrease the sediment-transport capability - the desired result being a reduction in bank erosion while still allowing moderate channel aggradation. In a stream that is aggrading, bank and channel stability may be restored by increasing the channel's sediment-transport capability, thereby transporting downstream any excess material delivered to the reach. Although channel modification can alleviate channel instability, using this technique without fully understanding its complexity (and that of the stream) could exacerbate existing problems or create new, more severe problems upstream and downstream. For this reason, it is absolutely essential that a qualified geomorphologist or engineer well versed in geomorphology be involved in channel-modification projects. For more information on site-based and reach-based causes of erosion and mechanisms of failure, refer to Chapter 2, *Site Assessment* and Chapter 3; and, for additional information about channel behavior and response, refer to Appendix F. Refer to the matrices in Chapter 5, *Identify and Select Solutions* for selection criteria of channel-modification techniques relative to various mechanisms and causes of failure.

Channel Profile and Planform Change

"Channel profile" is the slope, or gradient, of the channel bed. "Channel planform" is the shape of the channel looking down on it from above (referred to as "plan view"). One common descriptor of planform is "sinuosity," which is a measure of channel length relative to valley length. Whether a channel passes relatively straight through a valley or crisscrosses the valley several times is a function of its sinuosity. Sinuosity and profile are inseparable characteristics of a stream channel; its sinuosity is a function of its slope and vice versa. Adjustments to either slope or sinuosity will necessarily result in changes to the other. The exception to this rule is in channels with significant grade breaks, such as small dams or other drops, where slope can be changed significantly by removing the grade break. This type of change would not directly affect the channel's sinuosity. Additionally, changes to a stream's profile or plan will result in a change in its energy and sediment-transport capacity (see Appendix F).

Modification of the channel profile can occur by structurally altering channel planform or the channel slope. Channel slope can be increased by shortening the channel or decreased by lengthening the channel, depending upon the type of desired impacts to a reach. Channel shortening can best be accomplished by straightening a channel through a reach (reducing sinuosity). Channel lengthening can be accomplished by restoring a single meander or adding more meanders to a previously straightened channel. Modification treatments can also include the installation of drop structures that change the channel profile by increasing the channel-bed elevation at a certain point. This would reduce upstream slope and increase downstream slope.

Channel-Pattern Change

The most common channel patterns that occur naturally are straight, meandering and braided.[2] Several local and watershed-wide characteristics determine the pattern of a specific river reach, including hydrology, slope, bank structure, sediment, and the presence or absence of large woody debris. When any one of these factors changes enough to cross a threshold value, channel-pattern change may be abruptly initiated and usually results in a less stable channel system. In some cases, relatively small changes in climate or land use may trigger large changes in channel characteristics of natural streams.[3] For further discussion of the concept of geomorphic thresholds, refer to Appendix F.

Channel-pattern modification is used to force an unstable pattern into one that is likely to be more stable. This may entail changing the channel pattern from one form to another (e.g., from braided to meandering). Channel-pattern modification is a major undertaking, involving reconstruction of the channel bed, habitat features, channel banks and floodplain. Channel-pattern modification should be considered only where the existing pattern is in disequilibrium.

Channel Cross-Section Change

Changing a channel's cross section involves altering its bankfull width, depth or channel shape and can include modification of channel banks and bars. A common application of cross-section modification focuses on narrowing or widening a channel to effect a change in sediment transport by altering channel hydraulics. It can also be used to reduce shear stresses in a channel by reconstructing its floodplain. Another useful application of cross-section modification is to increase the availability and variety of fish habitat by creating asymmetrical features across the channel.

Narrowing a channel can also be beneficial in stabilizing a stream in disequilibrium, depending upon the particular circumstances at the site. This can be achieved artificially or by encouraging the channel to narrow itself by restoring vegetation and/or debris collection at the site or the addition of in-channel roughness elements.

If, on the other hand, a channel has become incised, it may become necessary to widen it. Widening efforts in such a situation would be used to develop a new floodplain surface that is connected to the channel at the new, incision-induced elevation.

Cross-section modification may also involve altering a channel bank slope to provide greater cross-sectional area. This involves excavating a bank and reshaping it from a steep or vertical face to a lower slope. Bank reshaping is a necessary component of several techniques described in these guidelines and provides a number of benefits to the stream system. Refer to the section in this chapter entitled, Bank Reshaping, for further discussion.

The removal of point bars is often perceived to be a beneficial cross section adjustment; however, its effectiveness is generally limited and temporary at best. Point bars are depositional features located on the inside of meander bends. While point bars and eroding banks evolve together, one does not generally create the other. They are simultaneous products of the channel flow-pattern. The channel planform creates the bend hydraulics. As the distribution of shear stress causes scour on the outside of the bend, it creates deposits on the inside of the bend. If the desired outcome of point-bar removal is to discourage bank erosion on the opposite side of a bend, it is not likely to have any lasting effect. It is also important to differentiate between point bars and midchannel bars, which evolve and influence stream flow differently. See Chapter 2 for additional information.

Although gravel-bar removal seldom provides any long-term protection for the opposite bank, it may temporarily reduce shear stress by increasing the cross-sectional area and reducing velocity. In order for this treatment to work, stream energy must be redirected downstream by lowering the water surface and straightening the channel. Point bars that are skimmed or removed, however, usually rebuild within the next flood season, and the cut bank may begin eroding again even before the end of that flood season. For only a temporary benefit at the project site, the unintended consequences generated in the upstream and downstream channel may be significant. It is important, therefore, to determine whether removal of a point bar is the correct solution for the problem, as well as if the impacts to the upstream and downstream reaches can be tolerated. Reaches with low bedload-transport rates and very stable downstream banks may be more tolerant of point-bar removal than others.

Cross-section change may also include the relocation and/or removal of levees to provide overbank flood relief. The removal of levees, if not planned well, can cause impacts comparable in magnitude to those of the initial levee installation. These implications must be well investigated and understood before attempting such a large-scale, cross-section adjustment.

Channel-Bed Elevation Change

The depth of a channel can be changed by raising or lowering its bed elevation. Bed elevation is linked to channel slope - if the bed elevation is changed, the channel profile must also change within the site, upstream and/or downstream. Channel-bed elevation changes are usually implemented by installing grade control, drop structures, roughness elements or steepened channel sections. Lowering the bed elevation is accomplished only through excavation (dredging) and has little practical application for establishing stream equilibrium or creating fish habitat.

Channel-bed elevation change is useful in restoring a degrading (incising) channel. An increase in bed elevation can aid in reconnecting the degraded channel to its floodplain. Degraded channels that are reconnected to an active floodplain become more stable because water depths and velocities in the channel are reduced. If flood flows spread out over the floodplain during relatively frequent floods (one- to five-year, return-interval events), channel erosion is minimized. Channels that are confined to ten-year or greater flood flows have sufficient energy to move large quantities of material. Massive channel erosion can occur if flood flow is confined within the channel during a 20-year or even 50-year flood event. Incised channels have a greater flow capacity, so that an even greater discharge level is needed for over bank flow. The results can be catastrophic in terms of bank and channel erosion, including the increased risk of catastrophic channel change. Therefore, raising the elevation of an incising channel bed should be seriously considered as an effective means of stabilizing it.

Channel Relocation

Channel relocation changes the location of the channel while preserving or recreating other characteristics, such as overall channel profile, pattern, cross section and bed elevation. The usual purpose of channel relocation is to move a channel away from an eroding bank. Relocation may also be used where a significant building or road is directly threatened by erosion. Channel relocation is often a means to solve problems of channel encroachment and/or confinement and to foster the development of a new, stable channel with healthy riparian buffers.

A channel can be entirely relocated to a new alignment, or just moved laterally within the existing alignment. One option is to deflect the flow laterally away from the hazard area using flow-realignment techniques (see the discussions in this chapter addressing *Groins, Barbs, Engineered Log Jams* and *Anchor Points*). Flow-realignment techniques should only be used in situations where there is no concern about impact to the channel, particularly the bank across from and downstream of the structure. Realignment techniques will change the meander shape locally and for some distance downstream, making appropriate site selection critical.

Emergency

Channel-modification treatments are not appropriate for emergency situations. Channel modification requires dewatering and careful analysis and design before implementation. However, it is possible to effect a change in channel alignment during an emergency using temporary groins. Refer to the discussion in this chapter addressing *Groins* for further information on their use and design.

EFFECTS

The potential effects of channel modification must be carefully assessed for a project reach. If implemented correctly, channel modification can restore natural features that fit the current and/or future conditions of the watershed. Erosion can be restored to a gradual and predictable rate, with habitat and other ecological conditions optimized.

When properly applied, channel-modification techniques can result in a one-time, cost-effective fix, preferable by far to the periodic and chronic fix alternative of treating one bank at a time. However, without a clear understanding of the complexities of channel-modification techniques and of the stream channel in question, problems may arise. Channel modification will generally result in changes to sediment-transport characteristics of a reach. For example, a decrease in stream gradient, resulting from channel lengthening, results in lower stream energy and may cause aggradation due to sediment deposition. This will result in a higher water surface during a flood, leading to more frequent inundation of the floodplain. Therefore, careful analysis and design are required.

DESIGN

Detailed designs are beyond the scope of this document because of the relative complexity and variability in channel-modification projects. A qualified geomorphologist or engineer well versed in geomorphology should be consulted to help evaluate the necessity and applicability of major channel-modification work and to assist in design.

At a minimum, field data collection should include the following seven elements:

1. stream gradient in the project area and adjacent reaches;
2. channel cross sections;
3. bedload and bed-material sizes;
4. streambank stratigraphy;
5. channel mapping with meander-belt width, meander wavelength, radius of curvature and sinuosity;
6. habitat mapping, including the influence of large woody debris, geology and confinements on channel character and habitat; and
7. floodplain mapping with topography.

An analysis of historic photos and maps can provide vital information for channel-modification work. However, if existing bank erosion is a result of changed hydrology or sediment supply, then historic photos cannot provide a basis for reconstruction. Careful analysis of the watershed should accompany any channel-modification work to determine if there has been significant alteration of the watershed hydrology. If urbanization, timber harvest, grazing, agriculture or other human activities have affected the watershed, the hydrology may be significantly and permanently altered. Natural changes such as fire should also be considered. Selection and design of channel-modification treatments should be based on historic photos only where changing watershed conditions can be accounted for, or where the watershed has already been restored to historic conditions. In any case, anticipated conditions for the long-term are a critical element of any channel modification design.

Reaches vulnerable to spontaneous channel-pattern change should be identified within flood-hazard management plans and watershed plans. Such reaches might be considered as possible off-site mitigation opportunities for other activities (see the discussion in this chapter addressing *Off-Channel Spawning and Rearing Habitat.*)

Reference Reach

The recommended design approach for channel-modification projects addressing site-specific erosion problems is based on the reference-reach concept (this approach assumes the reference reach is in a stable and unchanging watershed condition). A reference reach is a stable reach located either upstream or downstream of a project, or in a nearby watershed with similar hydrology, precipitation, soils, geology, relief, vegetation and land use. Applications for reference-reach design include channel modification to enhance or restore habitat and/or to address site-specific erosion problems.

If necessary, streams of differing size or drainage area can be used as reference reaches, as long as dimensionless parameters, such as width-to-depth ratio, are used. Several reference reaches might be used for added confidence. If a reference reach is not available, then regional hydraulic geometry relationships can be used to estimate channel dimensions, though this is not the preferred method.

Reference reaches may be used to generate a range of acceptable values for channel parameters such as pattern, plan and profile. However, whenever a reference-reach design approach is used, channel slope in both the reference reach and the design reach must be the same. Pattern, profile and dimensions of the project site are then compared to the reference reach. If the project reach varies significantly from the reference reach, it may be an indicator that channel modification is appropriate. The significance of variation can be roughly evaluated by comparison to the variance within relationships in regional hydraulic geometry data. Geometry and pattern of the constructed channel are then derived by correlation to the reference reach.

Habitat

Regardless of the design method used, there must be a component for habitat preservation or restoration included in the project. Habitat is directly associated with channel design in that most habitat features are inextricably linked to channel evolution and stability. Stable channels ideally provide sufficient habitat for wildlife and resident and migratory fish. However, because many components of a stable and natural system, such as large woody debris, may be absent, it will likely be necessary to install habitat features as part of the modification. Review Chapter 4, *Considerations for a Solution* in determining mitigation targets as a reference for quantifying habitat needs. Habitat must be designed as a self-perpetuating function rather than just as a feature. The hydraulics of the channel must support and maintain the habitat features intended, such that woody debris is recruited and retained, scour develops to form pools and gravels are sorted to form areas for spawning.

Debris

Debris and vegetation each perform significant roles in the evolution of channels, and their roles must be accommodated in the design of new channels. For instance, vegetation and large woody debris are historically abundant along streams in western Washington, so channel-modification techniques applied to streams there require the addition of large woody debris to restore natural processes. In eastern Washington, vegetation and large woody debris are less abundant, so large woody debris should be used only where it naturally occurs, or where habitat needs warrant its inclusion.

Riparian Planting

If riparian vegetation is damaged or limited in coverage, an extensive riparian-planting component should be included in the project. If livestock have access to the site, protecting the riparian corridor from them will be required to ensure success of the riparian plantings and long-term success of the project. Stockpiling fertile topsoil is critical for areas that will be highly disturbed. After the excavation and fill is complete, the topsoil can be replaced to provide an adequate base for riparian plantings. Refer to the discussions in this chapter addressing *Woody Plantings, Herbaceous Cover* and *Riparian-Buffer Management* and to Appendix H, *Planting Considerations and Erosion-Control Fabrics* for further information on riparian planting.

BIOLOGICAL CONSIDERATIONS

Restoring a stream to a more stable, natural shape can have tremendous benefits for fish and wildlife. If the floodplain is reactivated, the riparian community will be better able to re-establish and provide food and shelter for wildlife. Floodplain reactivation and the related increase in groundwater and surface-water interaction during summer and winter periods may also moderate water temperature extremes - a benefit to fish. Channel narrowing in combination with riparian-vegetation establishment might also moderate water-temperature extremes.

Channel modification can cause extensive, short-term disturbance to macroinvertebrates, amphibians, fish and some nesting birds due to instream disturbance, fine-sediment deposition, channel abandonment and loss of riparian vegetation. Although a stream with restored profile, pattern or cross section will provide better habitat in the long run, the necessary excavation, fill material and vegetative disturbance may cause substantial damage to existing habitat. If a stream channel is being completely moved or turned back into an historic meandering channel, much of the existing habitat can be lost for at least several years depending upon the stream system and ecoregion.

Fish trapping and relocation may be required to remove fish from the project construction area. The lower end of an existing channel might be left open and connected so there is instream habitat until the new channel is established with vegetation. A new channel may be left exposed for a winter so it can weather before flow is diverted into it.

Mitigation Requirements for the Technique

Mitigation may not be required for channel-modification treatments if there is a net habitat benefit created by the project. Mitigation may be required for one type of habitat that is replaced with another or for the time required for the habitat to become functional as described in Chapter 4. Impacts described in the previous section and associated with construction activities, site access and flow diversion may require mitigation. Refer to Matrix 3 in Chapter 5 for more detail on mitigation needs for this bank treatment.

Mitigation Benefits Provided by the Technique

Channel modification may provide substantial mitigation opportunities for spawning habitat, channel and habitat complexity and diversity, flood refuge, and lost opportunities associated with bank-protection projects elsewhere. Channel modification can greatly reduce the impact of bank-protection activities within a specific reach when compared to the alternative of cumulative impact due to chronic, individual, bank-protection projects throughout the reach. Refer to Matrix 3 in Chapter 5 for more detail on the mitigation benefits of this treatment.

RISK

Habitat

Channel-modification projects should be designed to provide habitat benefit. However, large-scale channel modification may result in temporary impacts to and loss of habitat due to disturbance. Months to years may be required for full recovery of some habitat components. There is a risk that a poorly designed channel-modification project may have a negative effect on habitat rather than a positive one. There is a trade-off between risk and habitat preservation and restoration as well. A channel must have a certain amount of deformability in order to sustain and generate quality habitat for fish. Additionally, a newly constructed channel that is not well protected by vegetative structure carries the risk that high-flow events could impact it and the downstream reach more severely than intended by the design.

Infrastructure

The intent of channel-modification treatments is to reduce channel instability and protect infrastructure. However, predicting the relationships among various channel attributes in the design and implementation of channel-modification treatments may result in risk to infrastructure if those predictions are inaccurate.

Reliability/Uncertainty of Technique

Because all channel-modification techniques result in changes to channel process, there is a risk that an inappropriate design or unanticipated conditions will cause a project to fail. A thorough understanding of fluvial geomorphology is an essential component of developing channel-modification projects. Refer to Appendix F for further discussion of channel planform and profile, pattern, cross section, and channel stability and equilibrium.

Materials Required

Construction of channel-modification projects will generally require dewatering of the channel either by diverting all flow or by isolating parts of the channel during construction. Dewatering is essential to facilitate construction and to control sediment inputs to the stream. Channel-modification projects are constructed using native materials available on site, through stockpiling, redistribution and rearrangement of existing channel materials. If large woody debris is not already present in the channel but is typical to streams in that region, it may have to be supplied from elsewhere. Many channel-modification projects require reconstruction of channel banks. Refer to specific bank-protection techniques in this chapter for descriptions of materials required for their construction. See Appendix M, *Construction Considerations* for additional information about construction.

Construction of channel-modification projects requires careful sequencing of work phases. Construction steps may include (not necessarily in this order):

- constructing a diversion channel;
- diverting stream flow;
- rescuing fish from areas to be dewatered;
- dewatering;
- gaining access to and stockpiling imported materials, waste materials and transitional, redistributed materials;
- restoring damaged banks and/or constructing new banks;
- installing erosion and sediment control;
- constructing and installing habitat features; and
- redirecting flow into the modified channel.

Further discussion of these components can be found in Appendix M.

Timing Considerations

Channel modification often requires complete dewatering. Consequently, the work should be timed to occur during low-water periods. Critical periods in resident and anadromous fish life cycles, such as spawning or migration, should also be avoided. Instream work windows vary among fish species and streams. Contact the Washington Department of Fish and Wildlife's Area Habitat Biologist for information on work windows (see Appendix B, *Washington Department of Fish and Wildlife Contact Information*). Further discussion of construction timing and dewatering can also be found in Appendix M.

Cost

Channel-modification project costs are site- and design-specific and vary according to the size of the channel. Reconstruction and relocation projects may range from $50 to $300 per foot of channel (including reconstructed banks and dewatering), depending upon the size of the channel and complexity of modification techniques. Key cost items will include dewatering systems, imported materials and bank reconstruction. Dewatering will be a significant cost for channel modification because it requires, in most cases, complete dewatering of the entire channel. The need to import materials for any component of the modification will greatly increase implementation costs. Since many channel-modification projects require reconstruction of channel banks, costs associated with acquiring bank-reconstruction materials will also need to be taken into account. Refer to Appendix L, *Cost of Techniques* for further discussion of bank-construction costs.

MAINTENANCE

Bank reconstruction and habitat elements associated with channel-modification projects require periodic inspection and maintenance or repair. They may be especially vulnerable to damage during the first years of operation, particularly if they are subjected to high flows before vegetative components are able to provide support. While the intent of channel modification is to create a stable channel, the design must allow some deformity to occur in order to create and sustain adequate fish habitat. For this reason, moderate erosion along banks should be expected and encouraged, and some degree of maintenance and repair should be anticipated, especially during the first three years of the new project. Refer to individual bank-protection techniques described in this chapter for additional information about deformity, maintenance and repair considerations.

MONITORING

Because channel-modification projects generally involve impacts to the channel and banks, they will require comprehensive monitoring of both channel and bank features, with particular attention to habitat monitoring.

Monitoring of channel-modification projects should be initiated prior to construction, with baseline-conditions surveys of the physical channel, its banks and its habitat value. This will allow comparison of modified conditions to pre-project conditions. Additionally, monitoring should include detailed as-built surveying and photo documentation of the project area and upstream and downstream reaches to allow for evaluation of performance relative to design. Refer to Appendix J, *Monitoring* for further discussion of monitoring considerations and practices. For a comprehensive review of habitat-monitoring protocols, refer to Johnson, et al.[4] Habitat-monitoring protocols will likely require a monitoring schedule that is more comprehensive than that required for the integrity of the structure.

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a. Channel Relocation to restore a channelized and eroding stream. Colony Creek, Tributary to Samish Bay, Puget Sound. 1999.

b. Floodplain terrace excavated and restored in a channelized and degrading stream. Austria.

Figure 6-48. Applications of channel modifications.

DESCRIPTION

The term "riparian" refers to that area adjacent to a river or stream that is physically linked to the moisture regime of the streamside environment. The riparian buffer usually extends from the stream's ordinary high water line to the outer edge of the floodplain. Riparian buffers provide essential functions for river and stream ecosystems, including cover and shade, a source of fine or coarse woody material, nutrients, and organic and inorganic debris that maintain stream ecosystem function. Riparian corridors also provide habitat for wildlife, especially migrating and breeding birds.

Riparian buffers enhance bank protection in a number of ways:

- Roots knit soil and sediment particles together into a matrix that resists erosion.
- Plant stems increase hydraulic roughness on channel banks and floodplains, slowing flow velocity and reducing scour.
- Large trees act as anchor points and buttress banks to resist failure.
- Inputs of large woody debris may roughen and stabilize the channel and provide improved fish and insect habitat (see Appendix F, *Fluvial Geomorphology* for further discussion).
- Riparian vegetation moderates the rate of lateral channel migration. For example, in a study of lowland streams around Puget Sound, C. W. May, et al., found that streambank stability is strongly correlated to the width of the riparian corridor and inversely related to the number of breaks in the riparian corridor.[1]

APPLICATION

The establishment of riparian buffers can be a primary technique of bank stabilization when the risk to property is low, and stable vegetation is all that is needed. For example, fencing cattle out of the riparian zone to allow vegetation to become re-established can often provide adequate bank protection. Riparian buffers can be applied as mitigation, or as a technique for bank-stabilization projects to provide long-term protection benefits. When used as a supplemental technique for other bank-protection measures, a riparian buffer will provide future bank protection as short-term, impermanent techniques such as log toes or engineered debris jams decompose and erode.

The creation or restoration of riparian buffers is considered a proactive bank-protection technique because restoring natural riparian function will mitigate future bank-stability problems. In agricultural areas for instance, where riparian vegetation is removed for the benefit of land cultivation, stream channels may migrate into the now-unprotected fields. Historically, man's response to such migration has been to apply bank hardening (e.g., riprap) to the migration site. Unfortunately, this will just accelerate lateral migration movement upstream or downstream, worsening the problem. A proactive approach would be to protect riparian vegetation in the first place or to restore it using woody structures or biotechnical erosion control to reinforce the bank as the plants grow (see Appendix H, *Planting Considerations and Erosion-Control Fabrics*).

Riparian buffers are only appropriate where land use does not preclude establishment and growth of riparian vegetation. See Chapter 2, *Site Assessment* for detailed information about site-assessment considerations and to Chapter 3, *Reach Assessment* for reach-assessment considerations. Additionally, Chapter 5, *Identify and Select Solutions* provides instruction on how to select appropriate techniques.

The most effective bank-protection alternative that also protects riparian habitat is one that limits land-use activities in this critical ecological zone. For instance, in an agricultural setting where live stock are present, the riparian buffer should be protected with fencing that keeps livestock out of the buffer zone, accompanied by a clear understanding and commitment on the part of the landowner that the fencing will be maintained. Changes in land use or conversions of the buffer zone that are not compatible with the needs of the stream will reduce a riparian area's effectiveness as bank protection.

In some instances, other considerations may take precedence over protecting or restoring habitat, such as riparian buffers within Federal Emergency Management Agency jurisdiction, where effects on flood elevations are a concern. Therefore, a full understanding of the setting and the potential implications of riparian restoration should be recognized as part of the feasibility analysis when considering this technique for bank protection.

Variations

Woody plantings, herbaceous cover and floodplain roughness are additional techniques that promote riparian buffer protection and development. Each of these techniques are discussed in detail in this chapter.

Emergency

Riparian-buffer management is not a technique that is effective in emergency situations. However, bank-stabilization techniques that are used during emergencies should be designed so that they will not rule out the potential for future buffer-management techniques to be applied at the site.

EFFECTS

Riparian buffers generally increase in-channel and riparian habitat value adjacent to the stream. A buffer may provide wood for recruitment, slow down flow velocities and reduce associated shear along banks and on the floodplain. Riparian buffers may increase floodwater surface elevations on the floodplain.

DESIGN

Floodplain Function

The most essential consideration for establishment of a riparian-buffer area is the soil-moisture regime within the buffer. Riparian plants depend on regular access to soil moisture through their roots and on occasional inundation by floodwaters to limit competition of nonriparian species. Evaluation of floodplain function is best determined by characterizing existing riparian plant community health. Incised channels may have a perched floodplain that restricts access of plants to the soil moisture.

Buffer Widths

The Washington Department of Fish and Wildlife makes several recommendations for riparian habitat area widths[2]:

- for Types 1 and 2 streams ("Shorelines of the State" and channels with widths greater than 20 feet), the buffer-zone width should be 250 feet on each side of the stream;
- for Type 3 channels that are five to 20 feet wide, the buffer-zone width should be 200 feet on each side of the stream; and
- for Type 3 channels that are less than five feet wide, the buffer-zone width should be 150 feet on each side of the stream.

These widths are applied to each side of the stream, starting at the ordinary high water line. The widths are set primarily for forested lands, with the objective of optimizing ecological benefits. Other widths may be more appropriate for other objectives, such as those that center on stabilizing a streambank only. It is best to determine an appropriate buffer width on the basis of site conditions and the best available science applicable to the area. On steep-gradient streams (two to four percent and greater), buffer widths may be narrower. Less then 32 feet of buffer is considered to be ineffective.[1] A. J. Castelle and colleagues found that 98 to 197 feet of buffer was adequate to control streambank erosion.[3] A. W. Johnson and D. M. Ryba recommend 98 feet of buffer to protect instream habitat, 98 to 164 feet for recruitment of large woody debris and 328 to 656 feet to benefit birds and mammals.[4]

Vegetation

Selection of appropriate vegetation is essential for viable riparian buffers. Plant selection should include the use of native species with diversity that insures a well-developed shrub layer and variability in tree age, shape and species. Appendix H provides more specific guidance on the selection and care of appropriate riparian plants. King County's *Guidelines for Bank Stabilization Projects*, has additional information on the selection of riparian plant species.[5]

Conducting an historical analysis of the area to be restored may be beneficial, particularly where all evidence of endemic vegetation and natural channel shape and process have been obscured by human activity.

Vegetation establishment often requires irrigation and weed control for success. Refer to the discussions in this chapter addressing the techniques *Woody Plantings* and *Herbaceous Cover* for additional information on cultivating and maintaining bank vegetation.

Conservation Easements

Conservation easements or other land-use controls can be beneficial and may be necessary to prevent incidental use and conversion of riparian areas to uses that are destructive to fish habitat in the stream. Conservation easements are legal, recorded documents providing continuous protection that carries forward even when the land is sold. They are voluntary agreements between the property owner and the holder of the easement that limit activities on the property (within the easement) in order to protect specified conservation values. The ownership of the land, however, remains with the private landowner.

Conservation easements are particularly important for long-term mitigation, where the mitigation must last for the life of the project. Various groups or agencies negotiate and/or provide compensation for conservation easements, such as local land trusts, conservations districts through Natural Resource Conservation Service programs and the Interagency Committee for Outdoor Recreation's Riparian Habitat Program.[6]

BIOLOGICAL CONSIDERATIONS

Mitigation Requirements of the Technique

No mitigation is required for this technique.

Mitigation Benefits Provided by the Technique

Because of its importance to fish and wildlife, restoration of riparian function may be considered mitigation for the loss of habitat caused by other types of bank-protection projects. The protection, restoration or creation of riparian buffers can be used as mitigation. Refer to Chapter 5 matrices for further information on the benefits of this treatment.

There are three components necessary for a riparian buffer to be considered acceptable as mitigation:

1. buffer widths must be defined in relation to stream type (as defined previously),
2. conservation easements must be provided, and
3. native riparian vegetation must be present.

Less-stringent requirements can be placed on buffers restored solely for bank protection or habitat enhancement and not as mitigation. The greatest benefit and full mitigation can only result from applying all three components.

When construction of a project leads to the destruction or displacement of upland vegetation, restoration is the appropriate mitigation. When a project confines a channel to an area narrower than the meander belt, one of the few mitigation opportunities available is to restore or improve the natural riparian function of the banks of adjacent reaches that might be affected by the confinement eventually.

RISK

Infrastructure

Development of riparian buffers may increase floodwater surface elevations compared to bare or smooth buffer zones. Hydraulic modeling of the possible impacts should be used to evaluate flood hazards to existing structures.

Reliability/Uncertainty of Technique

Development of riparian buffers is a reliable and proven technique. However, because robust development of plant growth depends upon soil conditions, climate and weather, site-specific outcomes are not easily predicted. There is risk in using the technique as bank protection due to the time it takes for vegetation to develop and function fully. Combining riparian-buffer management with other techniques that provide immediate protection often reduces this risk.

CONSTRUCTION CONSIDERATIONS

Materials Required

Establishment of a riparian buffer may require nothing more than restricting or minimizing land use within the buffer and allowing the stream to function naturally. The restoration or creation of riparian buffers may also require establishing or enhancing plant materials. This may include fostering the growth of existing plants or propagating them through natural recruitment. It may even require importing plant materials from other sites. Cultivation may require irrigation, mulch and soil amendments and may require riparian fencing. Refer to Appendix H for further information.

Timing Considerations

There are no timing restrictions other than those required to optimize plant propagation and survival.

Cost

Cost will depend upon the plant materials applied and the methods used to promote their growth. Direct costs include soil preparation, plant materials and installation, first-season irrigation and maintenance. Indirect costs may include establishment and administration of easements and fencing where livestock exclusion is necessary. The most significant costs of developing a riparian buffer may be in ensuring that there is a functional riparian hydrologic regime such as a channel elevation that supports groundwater access to the appropriate vegetation. If the channel is incised or entrenched, significant channel and/or floodplain restoration and manipulation may be required to restore functional riparian hydrologic regime. More information on cost of this technique is provided in Appendix L, *Cost of Techniques*.

MAINTENANCE

Propagation and promotion of plant growth may require irrigation and weed control. A maintenance plan should accompany all projects and should be written using other local projects as a guide, building on their methods of success as well as recognizing and avoiding techniques that have failed. The maintenance plan should be included in the monitoring plan (see next section); monitoring provides a means for determining when maintenance is necessary. This plan must be modified if monitoring indicates a high mortality rate for introduced vegetation. A clear threshold should be established for when replanting is required or when watering should be introduced due to reduced growth or high mortality.

MONITORING

Plant growth and mortality should be monitored annually, at a minimum, during the growing season. During the first year, and in arid areas, monitoring should be more frequent to identify and correct any problems early on. The monitoring plan should include criteria for initiating maintenance activities and should be correlated with the maintenance plan. The monitoring plan should indicate the methods used to quantify plant establishment and growth relative to design criteria and should include photo documentation from monumented photo points. Refer to Appendix J, *Monitoring* for further discussion of monitoring requirements.

For a comprehensive review of habitat-monitoring protocols, refer to Johnson, et al.[7] Habitat-monitoring protocols will likely require a monitoring schedule that is more comprehensive than that required for the integrity of the structure.

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Spawning-Habitat Restoration
Other Techniques

The Aquatic Habitat Guidelines program intends to publish a guideline entitled, "Stream Habitat Restoration Guidelines," in the near future, which will serve as the guideline series' most authoratative information on spawning habitat and off-channel spawning and rearing habitat.

DESCRIPTION

Spawning habitat is comprised of streambed gravel and the flow of water over and through the gravel. Spawning habitat includes any areas with substrate and hydraulic conditions suitable for spawning and adjacent cover habitat such as pools or woody debris. More importantly, the hydraulic conditions of the channel sort the gravel and create the conditions desired for spawning. Because spawning habitat is based on complex channel processes, spawning habitat may be difficult, if not impossible, to create in some situations. For this reason, spawning-habitat replacement as a mitigation technique has only limited application and should be done carefully and with full understanding of the potential biological implications. *Figure 6-49* shows various applications of restored spawning habitats.

Mitigation of spawning habitat that has degraded due to changes in land use must occur at a broad, watershed scale rather than at a site-specific level. For instance, mitigation for spawning habitat that is degraded in a watershed that has been clearcut requires a comprehensive investigation of changes in hydrology, as well as sediment production and transport, among other factors.

Various hydraulic projects can affect spawning habitat both directly and indirectly. Direct effects, which are often irreversible, include burying or covering spawning habitat with a bank-protection project or during construction activities. Channelization projects that shorten or abandon a portion of the channel also result in the reduction or elimination of spawning habitat. Indirect effects can include disruption of gravel recruitment from eroding banks and alteration of natural, channel-migration processes that create spawning habitat. Removing or reducing streambank and channel complexity can result in changes to the naturally occurring gravel-sorting process. Bank hardening can also result in lost opportunity by not allowing development of side channels and sloughs that often provide excellent spawning and rearing conditions. Any project that changes the flow, introduces sediment to a stream, or affects sediment characteristics can affect spawning habitat.

APPLICATION

Restoration or mitigation for damaged or degraded spawning habitats might include creation of instream habitat, off-channel habitat, spawning-gravel supplementation and/or cleaning spawning habitat that has been contaminated with fine sediment. Mitigation or restoration can be conducted at a specific site to correct and enhance localized conditions, or it can integrate stream- and sediment-transport processes for a larger-scale effect.

Designing projects that provide spawning habitat can be approached in two ways. One is to develop spawning criteria or suitability curves, maintaining a bed elevation using gravel of the proper size that will have acceptable depths and velocities at design flows.[1,2] This method is generally not practical except where flow is controlled (e.g., spawning channels with controlled flow and spring channels). The second approach, more common and preferred, is to mimic natural conditions and encourage stream processes that produce localized scour zones and tailouts with sorted gravels. The tailout of a pool provides a continuum of velocities and depths with changing flows, creating suitable holding and spawning habitat for a variety of fish species.

It is crucial to understand stream hydrology and local hydraulic conditions when undertaking a project that creates or enhances spawning habitat. The hydraulics ultimately sort and deposit gravel into spawning habitat. Hydrology and the supply of gravel to the site are also critical. A clear understanding of site and reach limitations will help define project objectives. Are limitations caused by channel character, such as low recruitment of debris that can create habitat? Are limitations created by a lack of spawning-gravel source? Site-specific projects are often unsuccessful, or have only limited success, when the designer does not consider or understand stream processes. An appreciation of sediment-transport dynamics within the watershed and at the site is critical to project success. For instance, projects relying on gravel supplementation can appear successful immediately after construction only to be destroyed after a high-flow event. For more information on sediment transport, refer to Chapter 3, *Reach Assessment*.

Spawning Pads

Spawning pads are short channel sections in which spawning gravel is placed either with or without other structures. They are placed in situations where high-flow hydraulics sort and maintain the gravel as spawning habitat. Some locations, such as constricted channels, are not appropriate for large, in-channel structures. For these sites, partial- or full-spanning bed controls, such as porous weirs and grade controls, may be the most appropriate method to retain the gravel needed to form spawning pads. Drop structures normally result in sediment deposition upstream of the structure and a creation of a gravel bar downstream at the tailout of the plunge pool. These drop structures are typically made of logs or large boulders. They are usually not appropriate for large or low-gradient channels that have well-developed riffle-pool morphology. Low-gradient channels that have a consistent and reliable source of groundwater generally make excellent locations for creating gravel spawning-pads because they do not typically experience high flows that could scour away placed gravel, and they have an abundance of rearing area.

Promotion of Spawning Habitat Adjacent to Bank Protection

The best bank-protection techniques that also protect spawning habitat are those that maintain or create diversity in the hydraulic characteristics along the streambank. This, in turn, leads to creation of more complex structures, which then develop scour holes, enable gravel sorting in the tailout and spawning habitat, and provide complex cover. Features such as engineered log jams are an example of a bank protection technique that can create spawning habitat from the tailout of the scour pool as shown in *Figure 6-50*. An exception to the use of large, complex structures in large rivers is where the bank is immediately adjacent to a known spawning area used by mass-spawning fish like pink or chum salmon. In that instance, a structure that is set back into the bank or a log revetment may have fewer impacts to spawning habitat.

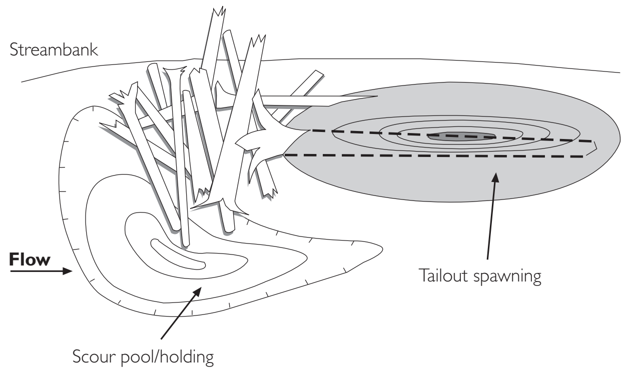

Figure 6-50. Spawning habitat created from tailout of scour pool.

In-Channel Structures

A channel may have an abundance of spawning gravel that is not being used because of the lack of cover for adult fish. In that instance, placing pieces of stable, large woody debris either in the bank or in the channel as cover structures will mitigate for some bank protection impacts. The cover structure must be large and complex enough to create and maintain a scour hole and stable enough to remain as long as the life of the bank-protection project. Cover logs can also be placed on the bank to span existing local scour holes.

Off-Channel Habitat

Another form of mitigation for bank protection is off-site construction of a side channel for spawning habitat. This may be as simple as reconnecting an abandoned side channel or oxbow, or it may involve excavating a new channel on a well-vegetated river bar. This technique has been widely used in Washington State and British Columbia.[3,4,5] See the technique discussed in this chapter entitled, *Off-Channel Spawning and Rearing Habitat*, for more information.

Spawning-Gravel Supplementation

Supplementation - the addition of spawning gravel to a stream - can increase usable habitat. The added gravel becomes hydraulically distributed in such a way that it creates new spawning habitat. The mechanisms of gravel and sediment transport in the watershed must be understood for a project like this to be successful (see Appendix D, *Hydrology* and Appendix E, *Hydraulics*). A reasonable estimate of gravel retention and/or distribution is critical to project success. Spawning gravel may be added to a channel in a variety of ways, including using a helicopter, conveyor belt or dump truck. It can also be deposited simply by placing a pile of properly sized gravel along the streambank and allowing high flows to entrain and distribute the gravel in the channel. In that case, the added gravel might be placed either to mimic an eroding gravel bank or a gravel bar. It may be necessary to add new gravel periodically.

Supplementation is usually undertaken in situations where recruitment of gravel is limited, and a shortage of spawning habitat has been documented. Examples include urbanized streams that have been armored extensively and channels that are affected by reservoirs. Supplementation is the only measure that can provide mitigation for the loss of a gravel source.

Cleaning Spawning Habitat

A variety of techniques have been used to reduce levels of fine-sediment deposition within spawning gravel. Ideally, techniques should be employed that remove and directly replace fine-grained sediment with clean, course gravels. Gravel-cleaning techniques are most useful only when a streambed has been adversely impacted by a single event or by a situation that has been corrected so recontamination won't occur. Rivers and streams with chronic, nonpoint-source pollution are not good candidates for gravel cleaning.

Rehabilitation of spawning gravels has usually been conducted on a relatively small scale in discrete reaches of a river. The simpler methods of gravel cleaning in the past involved the use of heavy equipment such as a bulldozer, backhoe or front-end loader to physically disturb the substrate. These methods aren't generally acceptable, however, due to the release of sediment and potential for contamination of other spawning habitat downstream. A channel bed is less stable following this type of cleaning, since the channel hydraulics will redistribute the bed material during subsequent high flows. Even so, there have been some successes worthy of note. R. J. Gerke[6] supervised the successful use of a bulldozer in cleaning spawning beds in several Washington rivers that suffered from heavy siltation caused by landslides. On the Cedar River, 29,000 square meters of gravels were cleaned using a bulldozer. About 3,000 sockeye salmon and 50 chinook salmon spawned following the cleaning operation. A section of the Entiat River in Washington was also successfully cleaned using a bulldozer, according to D. A. Wilson.[7] J. R. West reported that spawning by chinook salmon increased in Scott River in Northern California after gravels were cleaned there with a bulldozer.[8]

Another approach to the rehabilitation of spawning gravels incorporates the use of a hydraulic flushing action to mobilize and collect fine sediments. The "Riffle Sifter," developed in 1963 by the U.S. Forest Service, was the first machine designed to hydraulically clean sediment-choked spawning areas. The Riffle Sifter flushes fine sediments from the substrate by injecting a high-speed jet of water into the stream bed through a series of pipes. The apparatus then collects the fine sediments through a suction system and jets them onto the floodplain. The Riffle Sifter has been shown to remove up to 65 percent of the particles smaller than 0.4 mm.[9] However, it has developed several mechanical problems in the course of cleaning in natural streambeds.[10]

The "Gravel Gertie" was developed in 1979 by the Washington Department of Fisheries as a more advanced version of a hydraulic gravel-cleaning machine.[11] The Gravel Gertie is mounted on a low-bearing-pressure tracked vehicle that drives through the riffle during operation. The hydraulic cleaning action of the Gravel Gertie uses a vertical jet of water, which is directed towards the streambed to flush out fine sediments. A suction system within a rectangular collection hood removes fines from stream flow. The Gravel Gertie was field tested on the Palouse River in Northern Idaho and on Kennedy Creek and several other streams in western Washington. Effective cleaning was accomplished to substrate depths of 12 inches. All of these streams showed a decrease in the percentage of fines after one pass, with a reduction of fine sediments (<0.841 mm) ranging from three to 78 percent. These techniques are recommended only where material cannot be removed and replaced effectively.

Emergency

The restoration or creation of spawning habitat is rarely conducted under emergency conditions. Construction and enhancement of spawning habitat is typically conducted under low- or moderate-flow conditions. Careful design integrates the full consideration of stream hydrology and hydraulic conditions necessary to create and maintain the desired habitats. This is typically not advisable or even possible in an emergency situation.

EFFECTS

Modifications to channel characteristics by the addition of spawning gravel or gravel-retention structures can have unanticipated effects on banks and adjacent channel segments (see the techniques described in this chapter called *Channel Modifications, Porous Weirs,* and *Drop Structures,* and Appendix F, *Fluvial Geomorphology*).

DESIGN

Use of Large Woody Debris to Enhance Spawning

The enhancement of spawning habitat often relies on the placement of large woody debris to create the desired hydraulic conditions for sorting and retaining adequate quantity and quality of gravel (*Figures 6-51* and *6-52*). A log jam concentrates energy by acting either as a constriction or as an obstruction, resulting in the creation of a scour pool, with the tailout providing spawning habitat. Siting of log jams must be carefully planned because of their potential to increase in size and to alter the existing channel (see the technique described in this chapter called *Engineered Log Jams* and Appendix I, *Anchoring and Placement of Large Woody Debris*).

Spawning Pads

Spawning pads are usually installed in streams less than 40 feet wide. They are created by building a channel constriction or a drop structure across the channel, then placing a specified mix of spawning gravel upstream and/or downstream of the structure or allowing native gravel to deposit during high flows. Either structure creates a backwater upstream and a pool and tailout downstream that can collect gravel. The upstream gravel placement can also be designed to feed gravel to the tailout area. The channel constriction can create more diversity and intragravel flow than a cross-channel weir. It also has a much lower risk of creating a fish-passage barrier.

Spawning pads might be necessary where natural, woody debris has been removed and no structure exists within the stream channel to retain gravel in stable bars. They are usually built as a series of drop structures. Spacing between structures is based on channel gradient and the height of drop at each structure. The drop should be one foot or less during all flows occurring during periods of adult fish migration to facilitate fish passage. If juvenile fish passage is critical, the drop should not exceed six inches. If upstream juvenile fish passage is necessary, the drop required may be as small as six inches. However, structures with small drops are not as effective at sorting downstream gravel. In addition, the lower hydraulic head results in less intragravel flow. A potential risk with spawning pads is that spawners are often attracted to the newly placed gravel before it has had a chance to distribute hydraulically and stabilize. The eggs may not survive if the gravel in the spawning pad shifts during the first flood flows. Several high flows are needed to stabilize the spawning pad.

Channel constrictions can be used effectively to create spawning pads, but they should be considered only with a clear understanding of the dynamics of channel instability. Channel constrictions can create a backwater condition resulting in gravel deposition and ultimately lead to channel reconfiguration, a situation that creates spawning habitat but can also jeopardize bank stability. These dynamic processes are what naturally create spawning habitat. Constriction spawning pads usually only constrict the flow at moderate flood levels when gravel sorting occurs. They are generally constructed as low structures that will not constrict the channel during large floods.

A channel constriction is more effective in low-gradient, spring-fed channels than in a cross-channel structure. A channel constriction should be designed to increase velocities enough to keep fine sediment flushed out of gravels, maintain a tailout and be attractive to spawners. Spawning can occur in the constriction or at the tailout area. The spacing of constrictors is based on the channel gradient and the degree of backwatering developed by the constrictor. A common mistake is to place constrictors too close together, resulting in the backwatering of the upper constrictor, which, in turn leads to reducing velocities, thereby negating the intent of the application. Constriction design, including spacing and size, can be accomplished using either hydraulic models or through trial and error in the field.

An advantage of porous weirs and drop structures in creating spawning habitat is the high intragravel flow developed through the structure and bed upstream. However, this can be a problem if the stream experiences very low flow, and the entire flow goes subsurface. The standard log-drop-structure technique developed by the Washington Department of Fish and Wildlife is a good solution that has been effective and durable in many Washington streams over the last 15 years.[12]

Gravel Supplementation

Gravel supplementation can provide an alternative means of mitigating for degraded or lost spawning habitats. In reaches that are limited in gravel recruitment, a streambank or a gravel bar can be constructed of gravel and designed to erode, which provides a source of spawning gravel. However, because the lack of cohesion in a gravel-constructed bank, this application, if not well planned, can result in bank erosion. Other techniques add gravel directly to the stream and rely on high flows to distribute the gravels. A designer must consider sediment transport, hydrology and hydraulic conditions as well as channel morphology and structure. Refer to Appendix F for further discussion of gravel transport.

Groundwater Channels

Groundwater channels or off-channel, groundwater-fed channels, can be developed for both spawning and off-channel rearing habitat. These are low-gradient channels with low flows. Spawning usually occurs either at points of upwelling or on constructed spawning pads. If the native bed material is not the correct size, it will need to be replaced or supplemented with spawning gravel. Refer to the technique described in this chapter called *Off-Channel Spawning and Rearing Habitat* for information on the design of groundwater channels.

BIOLOGICAL CONSIDERATIONS

Mitigation Requirements for the Technique

Mitigation for construction-related impacts may be required depending upon the type of construction technique(s) used. Riparian habitats can be impacted by type of equipment and site access. Careful planning and the proper use of installation equipment (helicopter, conveyor, etc.) to distribute gravel can significantly reduce potential impacts. Dewatering - isolating the area under construction and removing water from it using a coffer-dam system - is required to control turbidity associated with in-channel excavation. Refer to Chapter 4, *Considerations for a Solution* and Matrix 3 in Chapter 5, *Identify and Select Solutions* for more detail on mitigation needs for this technique.

Mitigation Benefits Provided by the Technique

Spawning habitats are often the most difficult habitats to replace. Their stability and longevity are important to whether or not future generations of fish can and will use them. Longevity as habitat includes appropriate sorting of material and intra-gravel hydraulics. For this reason, it is crucial that the habitat-restoration project be designed in a way that it is self-maintaining.

Carefully planned and properly constructed instream and off-channel spawning habitats can also mitigate for lost or damaged juvenile rearing habitats and, to a lesser extent, adult holding habitats. Projects that integrate certain structural aspects, such as large woody debris, can produce diverse habitat for a variety of life stages and species of fish.

Refer to Matrix 3 in Chapter 5 for more detail on the mitigation benefits of this technique.

RISK

Habitat

Poorly designed and constructed projects may retain their utility for only a short period. Material (gravel, debris, boulders) selection is critical to the maintenance of the project over time. Newly placed spawning habitat is attractive to fish as perceived spawning habitat. If material is not properly placed or sized, or has not been hydraulically distributed, it can shift or even wash away after the fish have spawned, causing a loss of eggs. It is therefore important to take salmonid life cycles into account when scheduling installation (see information later in this technique discussion under *Timing Considerations*). Improperly sized gravels may also flush out, filling downstream habitats.

Infrastructure

With the exception of poorly installed large woody debris becoming dislodged, spawning-habitat enhancement poses minimal risk to existing infrastructure. There is some risk if channel constrictions or drop structures are placed without consideration or proper understanding of backwater and flooding implications, however.

Reliability/Uncertainty of Technique

Reliability and success is greatly increased when the finished project mimics natural conditions and allows for natural channel process and gravel mobility. Salmonids' spawning needs are highly particular, and replicating the necessary conditions is critical to project success. The creation of desirable spawning habitat for adults is in vain if conditions during egg incubation are unstable.

CONSTRUCTION CONSIDERATIONS

Materials Required

Large woody debris should be large enough to achieve the hydraulic effect necessary to create and maintain spawning habitat. Woody debris and boulders should be of sufficient size to be stable and perform their function of creating hydraulic conditions for gravel stability and/or retention.

The selection of correctly sized spawning gravels is also critical to the success of the project. The proper size of material should be determined first by hydraulic characteristics and then by spawning characteristics. Refer to Appendix E for further information on sediment transport. Angular or crushed gravels should not be used as spawning substrate. Rounded rock, uniformly graded from 0.25 to 3.0 inches in diameter, provides ideal spawning habitat for many salmonids in the Northwest. Specific mixes vary for sizes and species of fish and hydraulic conditions. The following table shows examples of gravel sizes and distributions for salmon.

Grain Size	Avulsion-Prevention Techniques		
	Chum, Pink	Coho, Fall Chinook	Coho, Fall Chinook
6"			100%
4"		100%	90%
3"	100%	85%	75%
1"	85%	55%	60%
0.25" to 0.75 "	40%	25%	20%

Table 6-2. Examples of spawning gravel mixes for salmon.

These mixes are intended for spawning only and are most suited for gravel supplementation or spring-fed channels where the gravel will not be greatly affected by flood flows. In other applications, it may be appropriate to augment spawning gravels with larger materials to add initial stability. The smaller material in the mix protects individual eggs by cradling the eggs. Eggs may be damaged in a mix of gravel with large open spaces.

Timing Considerations

Construction timing should avoid critical periods in resident and anadromous life cycles such as spawning, migration and egg incubation. Instream work windows vary among fish species and streams. Contact the Washington Department of Fish and Wildlife's Area Habitat Biologist for information on work windows (see Appendix B, *Washington Department of Fish and Wildlife Contact Information*). Further discussion of construction timing and dewatering can also be found in Appendix M, *Construction Considerations*.

Ideally, a newly constructed project should experience a high-flow season before fish are expected to use it as spawning habitat. High flows allow the placed gravel to sort and stabilize prior to its use for spawning.

Cost

Cost is highly variable in spawning restoration projects. Availability and delivery of materials contribute to variability in costs. A cost-saving option used by the Washington Department of Fish and Wildlife for obtaining spawning substrate is to sort gravels near the site. This technique involves the use of a mobile sorting operation positioned close to the project site. Delivery costs are significantly reduced using this method. Sorted and washed gravels may cost $20 to $40 per cubic yard.

Dewatering of a project site can add significant cost to a project. Dewatering costs are greatly affected by the size of the channel and other site-specific factors.

For further discussion of costs, refer to Appendix L, *Cost of Techniques*.

MAINTENANCE

If properly designed and constructed, a spawning habitat mitigation project should not require any maintenance. Gravel supplementation projects may require periodic additions of new gravel.

MONITORING

Biological monitoring provides the ultimate measures of project success. For a comprehensive review of habitat monitoring protocols, refer to Johnson, et al.[13] Monitoring the project for its integrity as a spawning site will likely require a more comprehensive schedule than that required for the integrity of the structures.

In addition to biological monitoring, monitoring the physical conditions is important to documenting project performance. Measurements of the degree of scour, distribution and abundance of gravel, gravel sorting, channel movement, composition of the spawning bed, and the condition of retention structures are recommended elements of a monitoring plan. Constructed spawning habitat, including bed forms and woody debris, can be carefully surveyed immediately after construction and again after initial high flows to document changes that might affect spawning success. Scour chains or other devices intended for measurement of spawning-gravel stability and scour can also be used. However, it is very difficult to quantify impacts of bed instability near hydraulic structures, since the hydraulics will be quite varied around the structure.

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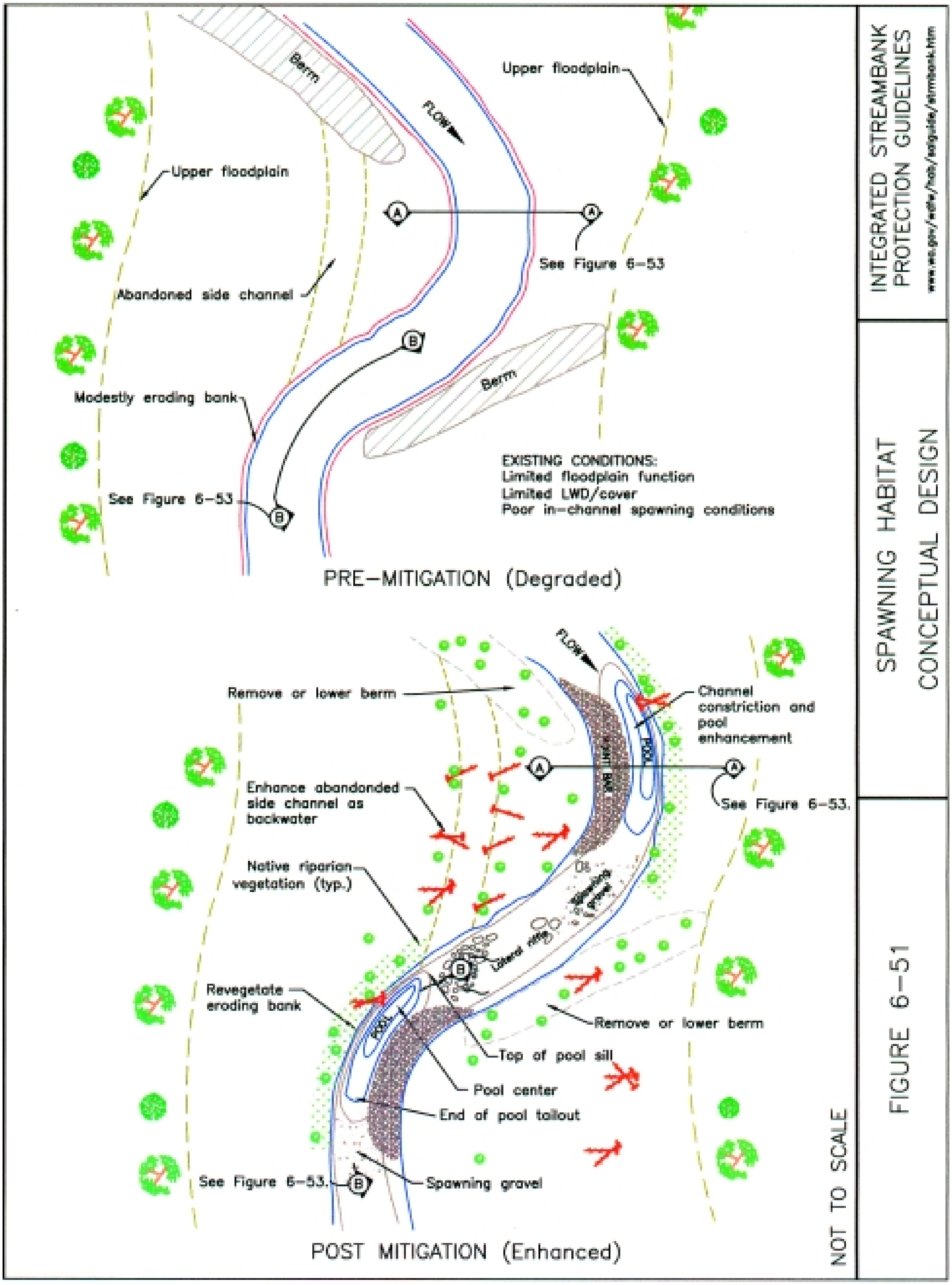
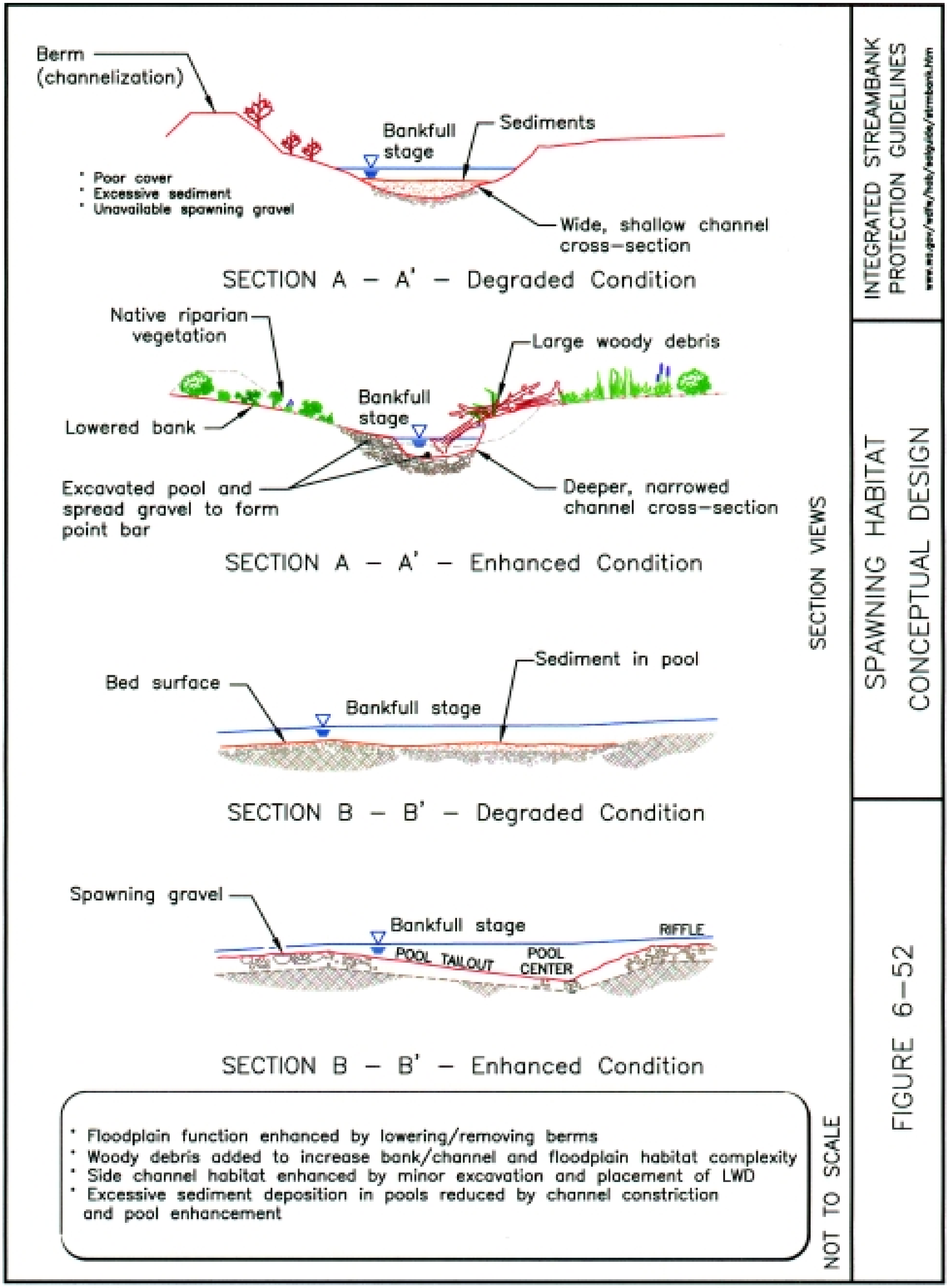
a. Unidentified stream in AK.

b. Spawning-Habitat Restoration upstream from bed control. Cedar Creek. 2001.

Figure 6-49. Applications of restored spawning habitats.


INTEGRATED STREAMBANK PROTECTION GUIDELINES
www.wa.gov/wdfw/hab/ahg/strmbank.htm
SPAWNING HABITAT CONCEPTUAL DESIGN
FIGURE 6–51
NOT TO SCALE
Berm
FLOW
Upper floodplain
Upper floodplain
See Figure 6–53
Abandoned side channel
Berm
Modestly eroding bank
See Figure 6–53
EXISTING CONDITIONS:
Limited floodplain function
Limited LWD/cover
Poor in–channel spawning conditions
PRE–MITIGATION (Degraded)
FLOW
Remove or lower berm
Channel constriction and pool enhancement
Point bar
Pool
Enhance abandoned side channel as backwater
See Figure 6–53.
Native riparian vegetation (typ.)
Spawning gravel
Lateral riffle
Revegetate eroding bank
Pool
Remove or lower berm
Top of pool sill
Pool center
End of pool tailout
See Figure 6–53.
Spawning gravel
POST MITIGATION (Enhanced)


Berm
(channelization)
Bankfull
stage
Sediments
Poor cover
Excessive sediment
Unavailable spawning gravel
Wide, shallow channel
cross-section
SECTION A – A' – Degraded Condition
Native riparian
vegetation
Large woody debris
Bankfull
stage
Lowered bank
Excavated pool and
spread gravel to form
point bar
Deeper, narrowed
channel cross-section
SECTION A – A' – Enhanced Condition
Sediment in pool
Bed surface
Bankfull stage
SECTION B – B' – Degraded Condition
Spawning gravel
Bankfull stage
RIFFLE
POOL TAILOUT
POOL
CENTER
SECTION B – B' – Enhanced Condition
Floodplain function enhanced by lowering/removing berms
Woody debris added to increase bank/channel and floodplain habitat complexity
Side channel habitat enhanced by minor excavation and placement of LWD
Excessive sediment deposition in pools reduced by channel constriction and pool enhancement
SECTION VIEWS
NOT TO SCALE
INTEGRATED STREAMBANK
PROTECTION GUIDELINES
SPAWNING HABITAT
CONCEPTUAL DESIGN
FIGURE 6–52

Off-Channel Spawning and Rearing Habitat
Other Techniques

The Aquatic Habitat Guidelines program intends to publish a guideline entitled, "Stream Habitat Restoration Guidelines," in the near future, which will serve as the guideline series' most authoratative information on spawning habitat and off-channel spawning and rearing habitat.

DESCRIPTION

Since 1980, salmon-habitat-enhancement programs in British Columbia and Washington State have given serious attention to the development of off-channel spawning and rearing habitat.[1,2,3] Projects have included restoration and modifications to river floodplain swales, abandoned side channels and floodplain channels along steep, terraced bluffs, all in order to increase spawning and rearing habitat.

P. N. Peterson and L. M. Reid[4] describe three types of habitat within a river floodplain:

1. overflow channels,
2. percolation-fed channels, and
3. wall-based channels.

Figure 6-53 shows various examples of these different types of off-channel features.

Overflow channels are very active and prone to frequent flooding. Percolation-fed channels are protected somewhat from flood flows and have the benefit of providing winter and summer refuge for juvenile fish and spawning habitat for adult fish. Wall-base channels often sit high in the river floodplain where they are protected from flood flows. They serve mainly as overwintering habitat for juvenile coho and trout.

APPLICATION

Off-channel spawning and rearing areas serve as mitigation for bank-protection projects that confine a channel (e.g., bank protection, bridges) and as habitat restoration. Rearing habitat can also be gained by providing access for juvenile fish to existing off-channel ponds.

Many types of bank-protection projects harden the bank of a river so that natural channel meandering cannot occur, thereby preventing the creation of new floodplain channels and fish habitat. Construction of off-channel spawning and rearing habitat may provide mitigation for the future loss of this habitat. Enhancing spawning and/or rearing habitat by developing groundwater-fed channels can result in significant production of coho and chum salmon.[5] If designed correctly, the lifespan of many of these channels can reach 20 years.

The primary objective in establishing groundwater or spring-fed channels is to provide quality habitat for spawning and/or rearing. The proportion of the site used to meet a particular fish life-cycle requirement can vary. It is site- and species-specific and should be based on mitigation requirements and/or on targeted fish species and limiting factors to their production in the watershed. Some sites are allocated and designed solely to function as spawning sites, whereas other sites may incorporate juvenile rearing and adult holding habitat into the design. Numerous variations are possible with this type of enhancement project relative to site conditions and biological considerations.

Variations

Overflow Channels

Overflow channels are flood swales that are directly connected to the main river channel during high flows. Fish habitat associated with overflow channels is often unstable and typically prone to flooding and channel shifting; however, periodic floods through these channels can also help maintain their productivity.

Percolation-Fed Channels

Percolation-fed channels are relict river and/or flood channels supplied by water that percolates as local groundwater from the river. They are usually somewhat protected from floods, can provide ideal sites for spawning-habitat enhancement and provide winter and summer refuge for juvenile fish.

Wall-Based Channels

Wall-based channels can be groundwater-fed but are often fed from springs or surface water from the adjacent terrace. They are usually higher in elevation relative to percolation-fed channels. Wall based-channels can often be enhanced to provide excellent rearing and overwintering habitat for certain species of juvenile salmonids.[6]

EFFECTS

A carefully designed, groundwater-fed side channel at a suitable site can provide spawning and year-round rearing habitats. Furthermore, groundwater-fed channels are often protected from frequent flooding. This stability enhances the success of the project. However, catastrophic flow events that reach the channel can headcut through to the river mainstem and encourage avulsions. These floods can potentially alter habitat conditions, scour the streambed and destroy incubating eggs.

DESIGN

The following design components are important to the development of successful off-channel habitat. *Figure 6-54* shows a conceptual design drawing.

Site Selection and Inventory

The site can be selected from an inventory of site opportunities. Such an inventory should be compiled as part of watershed-restoration planning or flood-hazard management planning. Potential sites should be identified from aerial photos and U. S. Geological Service quad maps. Confirm potential sites by conducting a field survey, and identify any swales or depressions within the floodplain that are protected from frequent river flooding but appear to be deep enough to be near groundwater.

Identify and characterize nearby surface water sources. Identify likely areas in the main channel into which the side-channel flow can discharge to attract fish to the site. The preferred location for a channel outlet is at a point where the channel approaches a terrace at the downstream end of a bend. At such locations, a natural river pool is often present to provide a fish holding and transition area into the side channel, and the location is most protected against closure by river bar deposits. These areas can also be created or enhanced by placing scour structures such as boulders or debris jams in the channel outlet.

Survey

Survey the river's water-surface elevations upstream, adjacent to and downstream of the proposed side channel site. Record elevations of any surface water within the project area. Record recent high water marks, and estimate the return period based on past records. Set elevation reference points at the three locations, and tie the elevations together with a survey that includes elevation reference points for other fieldwork on the project site. For off-channel rearing ponds above the river floodplain, measure the proposed pond elevation relative to the access channel to determine the type and magnitude of channel modifications to ensure fish passage.

Evaluate Percolation Capabilities

The amount of percolation flow may determine the success of the project. Observe and evaluate soil characteristics and percolation capabilities. Dig test pits, analyze percolation, and test water chemistry to determine the nature of soils, the potential of groundwater flow, and the temperature and quality of the water. Record descriptions of the soils, and survey the elevation of soil strata in the test pits.

Pump tests may be necessary to predict percolation rates more accurately. Since analytical hydrologic methods are not available for spring flows, direct flow measurements should be made for a period of a year. A flow-measuring weir can be installed, but be aware that a slight change in water surface elevation can significantly change the volume of measured flow.

To accurately quantify groundwater-flow potential, an extensive aquifer test with at least several high-capacity wells and a long-period, high-capacity pump test is required. The Washington Department of Fish and Wildlife has developed a simple pump-test method of evaluating groundwater-flow potential. This pump-test procedure simplifies the assessment of the groundwater by making the assumption that the water is unconfined. Restated, the aquifer has no impermeable boundaries. This method calculates relative aquifer permeability and relative aquifer supply rates.

Water is pumped from a test pit excavated by backhoe. Two parameters are used to analyze the groundwater potential: drawdown index and apparent velocity. The drawdown index is the pump rate divided by the drawdown rate, and the apparent velocity is the pump rate divided by the wetted area of the test pit. These parameters have been measured for 12 different projects, and comparative ratings have been developed.[7] Piezometers should be installed in the test pits and at additional sites along the proposed channel alignment.

Monitor Water Levels

River and groundwater levels and/or flows should be monitored during a wide range of river flows (at least three per monitoring site) and seasons. This usually requires a period of one year to cover winter and summer groundwater levels. These measurements can then be used to determine channel-control elevations, the depth of excavation and the potential of backwater effects from the river downstream.

For groundwater-fed channels, the design of the channel elevation requires balancing the optimum water surface elevation for maximum groundwater flow against the potential that the channel will be backwatered too frequently from the river mainstem. Percolation flow and concomitant upwelling intergravel flow are reduced when the channel is backwatered. The channel should operate most of the time without backwater effects from the river unless strong upwelling is expected to continue. The channel should be designed to maintain surface flow during summer months.

Once the design elevation is selected at the upstream end of the channel, the gradient of the channel can be selected. Log or plank weirs are usually installed to provide water depths throughout the channel from 0.7 to 3.0 feet. Required channel depth is often species-specific. Water-level controls should be designed with drop structures of less than six inches to ensure passage for juvenile fish and to minimize loss of flow around the structures. Since the structures are built in a porous bed, it is often difficult to maintain flow over a water-control structure that is higher. Water-level controls such as log weirs need to be sealed with an impervious geotextile material to prevent loss of flow over the control and loss of fish passage there.

Generally, channel widths should be in the range of eight to 20 feet and may be restricted by the type of excavation equipment used. Cost is directly driven by channel width.

Physical Habitat

Physical habitat features such as spawning gravel and woody debris should be incorporated into the design. Exposed gravel in the channel can be used, or processed material can be imported. Many channels have provided successful spawning habitat using existing substrate. Evaluate the presence and quantity of potential spawning gravel during excavation of the initial project test pits. It may be economically viable to screen gravel from the overburden for use as spawning bed material. During construction of the channel, a layer of sand will likely accumulate on the gravel bed. It may have to be cleaned with a gravel-cleaning machine.

Cover structures should be located throughout the channel to provide refuge for adult and juvenile fish. Intermittent deep pools can be provided with cover for adult fish holding. Riparian structures should be built into the banks of the channel.

Water Supply

A channel that is fed primarily by groundwater flow provides a more stable environment for incubation and rearing than does a channel that relies solely on surface flow. Flow conditions and water temperatures are more consistent and predictable in channels fed by groundwater. Furthermore, groundwater-fed channels run warmer and clearer in the winter, providing better prey production and feeding opportunities and a less harsh overwintering habitat.

A hydraulic gradient is created when a channel or pond that is excavated into the water table with the channel outlet and water level control elevation below the static water level. This hydraulic gradient controls the amount of surface water flow and is an important parameter in the success of a project. The gradient has much more influence than does the area of the channel or the depth of the channel bed. The amount of flow can be a controlling factor for adult usage and juvenile recruitment. Furthermore, the amount of inter-gravel flow is also closely related to egg-through-fry survival.[6,8] The quantity of groundwater flow is important, so it is desirable to make preproject estimates of the flow potential.[7]

BIOLOGICAL CONSIDERATIONS

Mitigation Requirements for the Technique

This technique is typically used as a form of mitigation for lost or degraded spawning and rearing habitats. Mitigation for construction-related impacts or impacts to wildlife might be required.

It's important to note that an excavated channel can affect the local groundwater level. There is a potential that wetlands may be drained, and vegetation characteristics of the floodplain can be adversely affected. These impacts can be roughly estimated with an accurate assessment of groundwater conditions and anticipated changes. Refer to Chapter 4, *Considerations for a Solution* and Matrix 3 in Chapter 5, *Identify and Select Solutions* for more detail on mitigation needs for this treatment.

Mitigation Benefits Provided by the Technique

Use of this technique may have significant restoration or mitigation potential in watersheds where off-channel rearing and/or spawning are limiting factors to overall fish production or where mitigation is needed for lost opportunity. Creating successful spawning and rearing habitat can result in production of many generations of fish. Refer to Matrix 3 in Chapter 5 for more detail on the mitigation uses of this bank treatment.

RISK AND UNCERTAINTY

Risk to Habitat

Risks to habitat associated with this technique are low, primarily because the work is done out of the main river channel and often in what is initially an upland area. There is a risk of beavers changing the channel-control elevation and the channel or pond becoming contaminated with sediment. There is a risk of stranding fish if elevations and flows are not correctly estimated and surface flow is lost from portions of the project. Over time, leafy material from trees and fine sediment may accumulate and limit productivity or fish passage. These processes are usually part of the natural evolution of side channels. Some maintenance is needed to ensure continued operation at an optimum sole-purpose habitat.

Infastructure

There is also some risk when excavating in the floodplain that major shifts in the river could capture the constructed channel during a large flood. The site and reach assessment and project design should take this risk into account and the risk to infastructure should thus occur. Separation of the constructed channel from the river channel will reduce risk of avulsion. Constrictions made of boulders and/or debris within a constructed side channel can control how much flow it can pass and thereby reduce the risk of avulsion. Constructed spillways in areas where floodwaters will enter the side channel can help lessen the risk of headcuts forming at those places. See the techniques discussed in this chapter entitled, *Floodplain Roughness, Drop Structures, Floodplain Flow Spreaders, and Riparian-Buffer Management* for ideas that can supplement channel construction to manage risk.

Reliability/Uncertainty of Technique

This technique, while proven successful, does rely on the assumption that a consistent and reliable source of groundwater is available. Adequate site assessment as described earlier in this technique discussion can minimize any uncertainty as to the presence and quantity of groundwater available. Changes in land use should also be kept in mind as they may alter groundwater dynamics.

CONSTRUCTION CONSIDERATIONS

Off-channel spawning and rearing habitat is usually constructed outside of the active river channel and therefore requires less attention to factors that complicate construction at sites with moving water. If a channel is to be constructed in a surface-water channel or in a spring-fed channel with substantial flow, a thorough plan for project sequencing and care of the water must be developed. This might include using temporary closure berms to isolate work areas, pumping water onto the forest floor or into settling basins and installing substantial filter devices to clean water that will discharge into the main river. Factors such as access, materials availability, equipment, labor and sediment control must be considered. Further discussion of these elements is provided in Appendix M, *Construction Considerations*.

Clean and correctly sized spawning gravel is critical to the success of a groundwater-fed spawning channel. Washed, rounded rock, generally 0.25 to 3.0 inches in diameter, provides ideal spawning habitat for many salmonids in the Northwest. Angular or crushed gravels should never be used as spawning substrate. Specific spawning-gravel mixtures are addressed in the technique discussed in this chapter entitled, *Spawning Habitat*.

If the channel sub-base material is sandy or clayey, a gravel filter or geotextile blanket is often required to support imported spawning gravel. Additionally, special, low-bearing-pressure equipment may have to be used for at least part of the excavation. Any debris should be anchored to accommodate large fluctuations in main-channel water levels that backwater the side channel.

Timing Considerations

Timing considerations are less of an issue in the establishment of off-channel habitat because the projects are usually somewhat removed from nearby bodies of water. Construction should be conducted when potential impacts to migrating or spawning fish are minimized. Additionally, construction should occur during seasons of low groundwater levels to facilitate construction. Contact the Washington Department of Fish and Wildlife's Area Habitat Biologist for information on work windows (see Appendix B, *Washington Department of Fish and Wildlife Contact Information*).

Cost

Cost is highly variable in spawning and rearing habitat restoration projects. Location of spoil piles, availability and delivery of gravel and large, woody debris, and site access are the primary factors that result in variable costs. One option used by the Washington Department of Fish and Wildlife to obtain spawning substrate is to sort gravels near the site. This technique involves the use of a mobile sorting operation located within close proximity to the project site. This technique significantly reduces delivery costs. Using on-site materials, construction costs may range from as little as $6 to $8 per cubic yard of material excavated, which includes bed controls, habitat structures and revegetation. However, imported gravel may cost $40 to $60 per cubic yard.

For further discussion of costs associated with off-channel spawning, refer to Appendix L, *Cost of Techniques*, which describes costs associated with wood materials and complementary project components, such as creation of large woody debris jams.

MAINTENANCE

Maintenance is minimal with this type of project; however, fine sediment and organic debris that can accumulate in the gravel bed may require periodic cleaning of gravel and/or supplementation with new gravel to maintain or restore full habitat potential.

MONITORING

Biological monitoring provides the ultimate measure of project success. Annual spawner counts are the most direct measure of project success. Trapping juvenile fish as they enter and leave a site will be necessary to evaluate the rearing use of a channel. For a comprehensive review of habitat monitoring protocols, refer to Johnson, et al.[9] Habitat-monitoring protocols will likely require a monitoring schedule that is more comprehensive than that required for the integrity of the structure.

In addition to biological monitoring, the monitoring of physical conditions is important to the documentation of project success. Periodic flow measurements in the channel will determine whether the flow is constant or diminishes over time. Analysis of sediment in the gravel bed can be used to evaluate its quality over time. An evaluation of potential headcutting should be done after large floods occur that are high enough to enter the channel.

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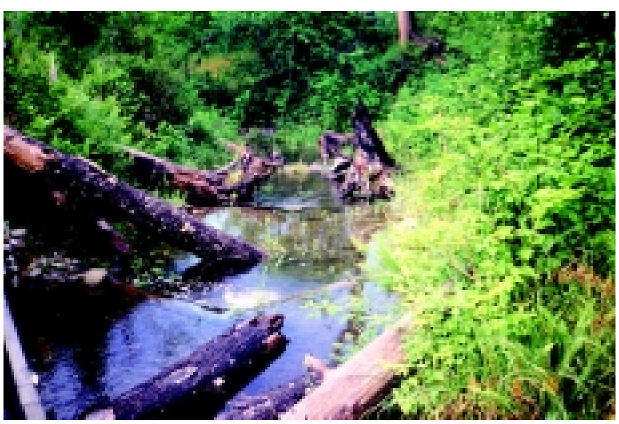
a. Before construction, Creamer Slough, Tributary to Satsop River. 1998.

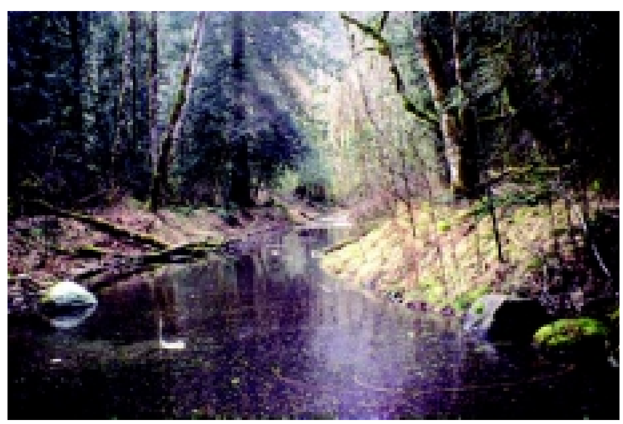
b. After construction of Off-Channel Spawning, Creamer Slough, Tributary to Satsop River. 1998.



c. Hoh Springs. 1993.

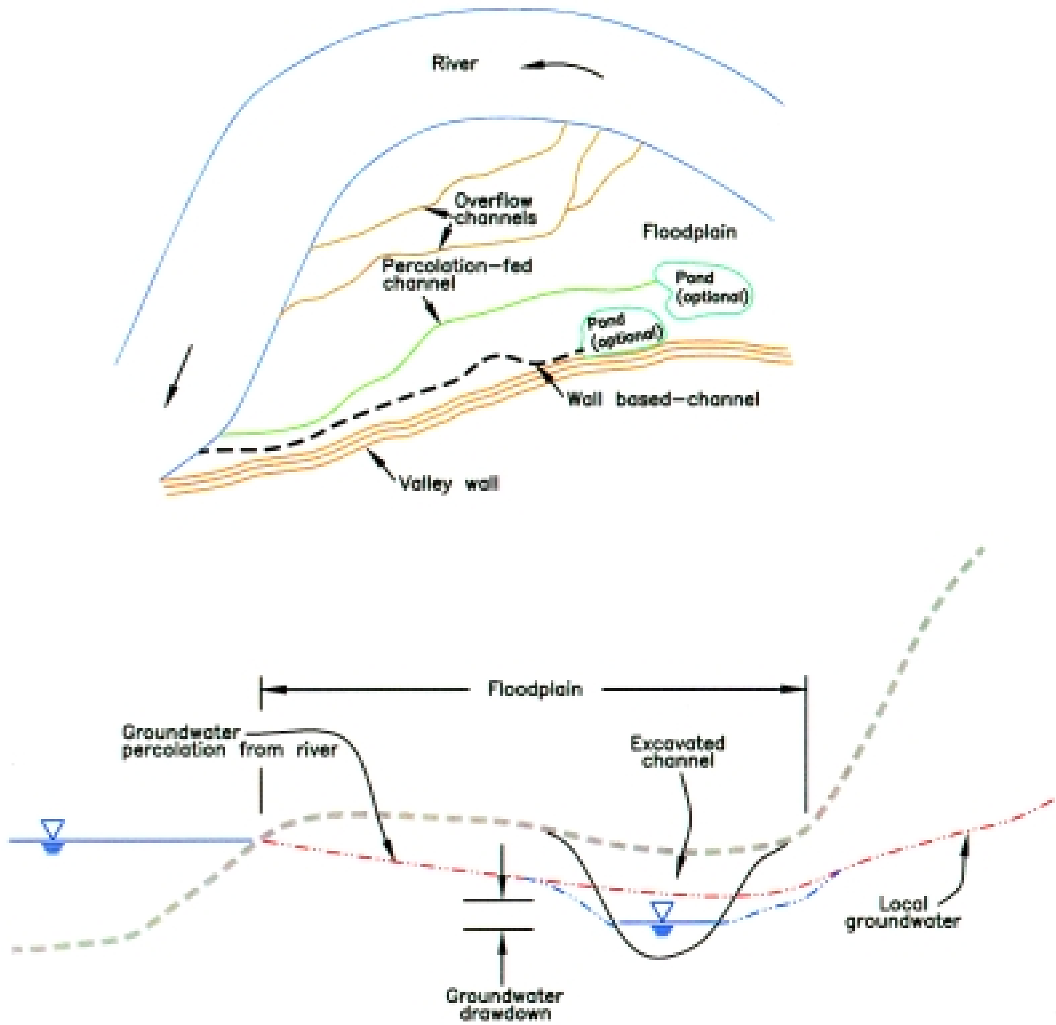
d. During construction, Creamer Slough, Tributary to Satsop River. 1998.

e. Calawah Springs. 1993.



f. Park Slough, Skagit River. 1990.

Figure 6-53. Various examples of off-channel spawning and rearing habitat restoration.



NOT TO SCALE

FIGURE 6-54

OFF-CHANNEL SPAWNING & REARING HABITAT CONCEPTUAL DESIGN

INTEGRATED STREAMBANK PROTECTION GUIDELINES

www.wa.gov/wdfw/hab/ahg/strmbank.htm

APPENDICES >>>
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