CHAPTER 7

DESIGN GUIDELINES

While there are many effective means of bank erosion control available, not all techniques work equally well in every situation. Many ineffective techniques are used as quick solutions to long-term problems. To choose the best solution, a match must be made between the objectives of the project, existing site conditions, possible techniques, and fish and wildlife habitat concerns.

Only after the cause of the failure has been clearly defined should a bank stabilization plan be prepared. Bank stabilization projects fall in two broad categories: those that correct the problem and those that compensate for it. Even though the most effective way to stabilize a bank is to eliminate the cause of the instability, measures to compensate for a problem are often used in addition to or instead of correcting the fundamental cause. It is vital to ensure that the proposed project solves or helps solve the problem before proceeding with the project.

As mentioned previously, because of the complexity of most bank failures, integrated, interdisciplinary, effective teamwork is required at all project stages. Knowledge of many aspects of riverine environments is essential if bank stabilization projects are to be successful. Again, it is strongly recommended that a team approach be used when developing or reviewing possible bank stabilization projects. The nature of the project will likely dictate the most suitable qualifications or experience required of the team. At a minimum, the team consisting of an engineer with experience in river systems, an ecologist knowledgeable in fisheries and riparian ecology, and a soil scientist will generate the most successful projects. Some projects may require the specialized skills of a geomorphologist, botanist, or landscape architect.

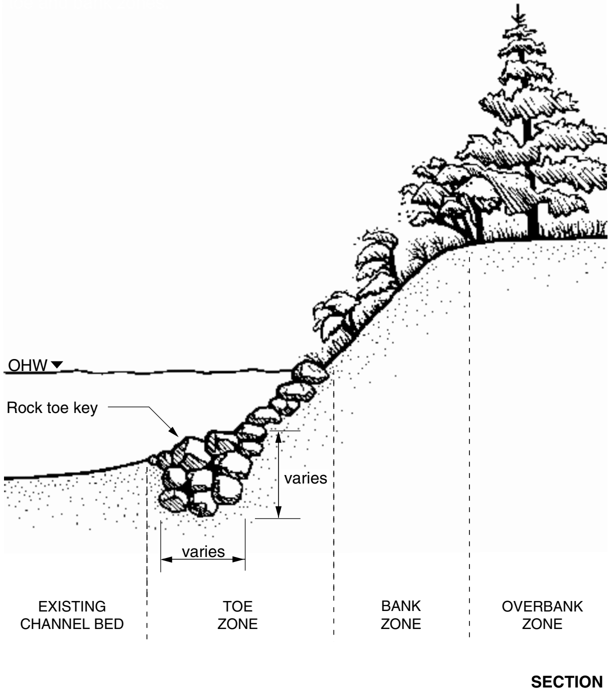
Although the streambank zones above and below the ordinary high water mark are treated separately in these guidelines for organizational reasons, it is important that the entire bank be considered as a single entity. Toe protection and vegetative components must be incorporated into a single design with an appropriate transition at their common boundary. It is also important that the geometry and hydraulic characteristics of the stream channel in all three perspectives (cross-section, plan view, and profile) be fully examined and investigated. This understanding of the stream is essential to achieve a successful integration of the project with the natural channel.

This chapter describes basic design considerations and criteria for rock, vegetated, and integrated (i.e., vegetation, soil, and rock) methods for bank stabilization. Also included in this chapter are suggested habitat components for these methods, and a brief discussion on preparing design drawings, plans, and specifications.

7.1 STREAMBANK ZONES

As discussed in Chapter 3, streambanks can be divided into three zones: the toe zone, bank zone, and overbank areas (Figure 3.1 and Figure 7.1).

Figure 7.1 A bank stabilization project with a rock toe key.



This section summarizes the characteristics of these three zones, focusing particularly on the design implications for each zone.

7.1.1 TOE ZONE

The toe zone, which is the area of bank below the ordinary high water mark (OHWM), is usually inundated and subject to toe erosion and undercutting of the bank. Because of the harsh conditions in this, woody vegetation generally does not grow here; as such, bank stabilization methods that rely primarily on vegetation are not particularly effective. Methods that are commonly used to stabilize this zone are rock toe keys, cribwalls, and large woody debris.

7.1.2 BANK AND OVERBANK ZONES

The bank zone, which is between the OHWM and the top of the bank, is inundated during periods of moderate (i.e., up to bankfull) flows and exposed to periodic erosive currents and debris movement. Woody and herbaceous vegetation grow well here. All three bank stabilization methods mentioned above (rock, vegetative, and integrated) may be used in this zone.

The overbank zone is the area landward of the top of bank which is subjected to occasional inundation during flood flows. Important considerations in this zone, where riparian vegetation transitions into upland areas, are wildlife habitat and access for project construction and long-term maintenance.

Most stream channels have complex cross sections. Often there are one or more small channels that concentrate flow during low flow periods and a larger channel in which flows are confined most of the time. Low flow channels are often flanked by one or more sand or gravel bars that may lack permanent vegetation. Active channels are generally flanked by sedimentary berms or erosional scarps covered with perennial vegetation. Compound, multi-sloped banks tend to be more stable than simple, single-sloped banks because berms reduce effective bank height and provide extra toe support for the upper bank.

7.2. DESIGN OPTIONS AND CRITERIA FOR DIFFERENT METHODS

Bank stabilization methods can be categorized into three fundamental types: rock, vegetative, and integrated. Rock methods are those that rely on riprap and/or large boulders to armor the toe and sometimes the bank, or redirect erosive flows. Vegetative methods are those that use plants or plant cuttings to stabilize the bank. Integrated methods are those that incorporate various materials (rock, timber, soil, and plants). In combination with these materials, integrated methods may also include fabrics such as jute or coir mesh.

To help designers in selecting solutions appropriate for each situation, the following discussion provides basic descriptions of each method and general selection criteria. Installation procedures, including relative quantities of material required and construction techniques, are discussed in Chapter 8.

7.2.1 GENERAL DESIGN CONSIDERATIONS

There are many factors to consider when selecting a design option. Among these factors are the stream characteristics (cross-sectional dimensions, flow depth, velocity [both magnitude and direction] and slope of bed or bankline being protected). Construction techniques and methods to minimize adverse impacts to the riparian environment should also be considered.

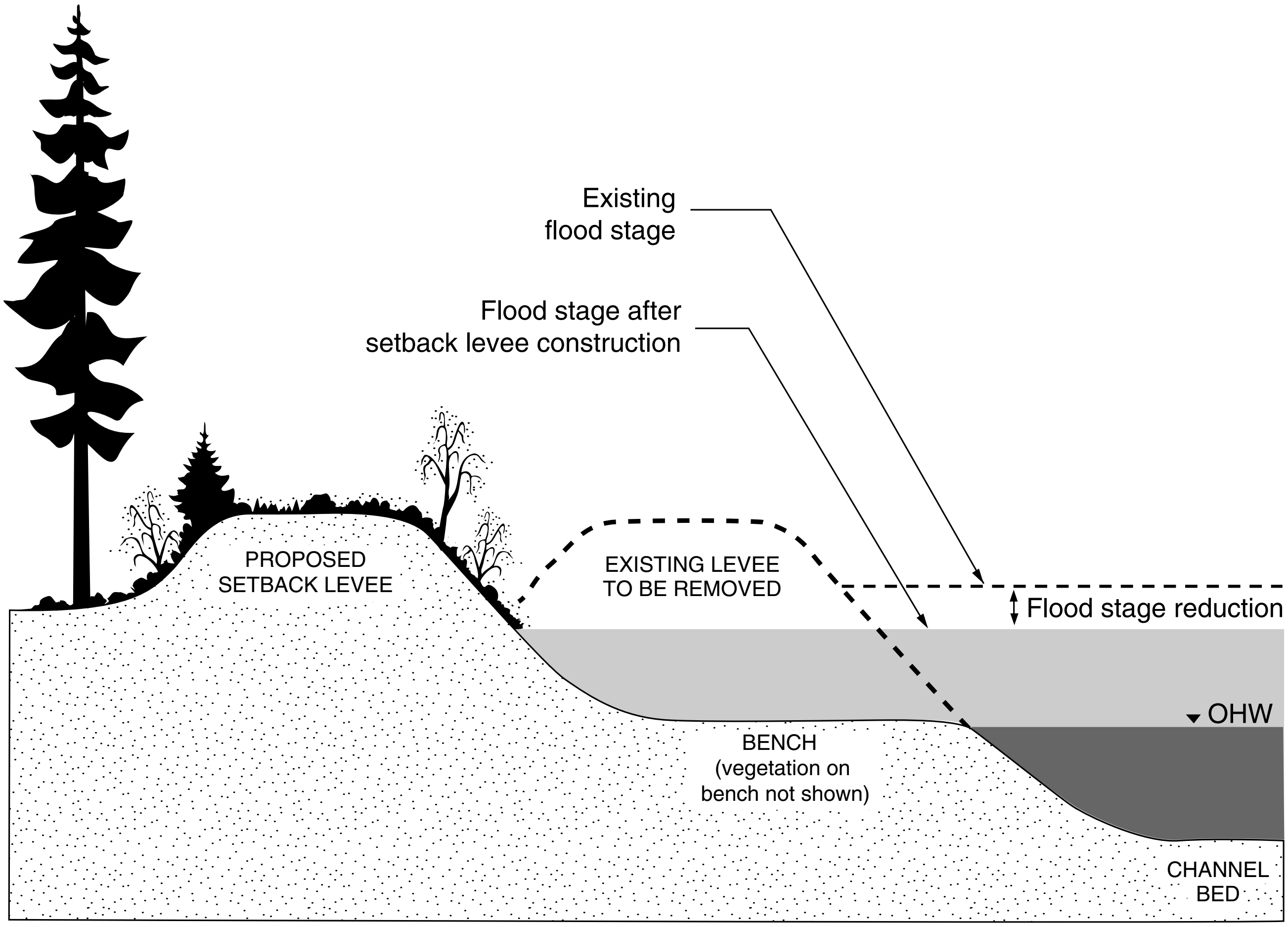
Location of the Structure. Most King County levees and revetments were constructed along natural channel banks to convert as much of the floodplain as possible for other uses. Recently, recognizing the benefits of floodplain conveyance and storage, and the drawbacks inherent in encroachment on the channel, this policy has changed. (See discussion of King County Sensitive Area Ordinance in Chapter 5). Current practice, whenever possible, is to set back at least the upper bank of any new facility from the main channel. The toe section can be built at the location of the existing bank, with a bench constructed at the ordinary high water line, and the upper bank set back. Figure 7.2 illustrates a setback levee with a vegetated bench. In time, vegetation planted on the bench will extend out over the river to provide shade and cover along the stream margin for fish.

Bank Sloping. Most methods of streambank protection will require some bank regrading. Steep or undercut banks may require regrading the slope to 2H:1V or flatter. Because of their unconsolidated nature, streambanks with sandy soils may require slopes of 4H:1V or flatter. The application of methods that require extensive bank sloping may be limited by the close proximity of structures (i.e., buildings, roads, utilities), loss of vegetation of significant size (i.e., large trees), land acquisition or easements. In these situations, a rock wall, live cribwall or vegetated geogrid could be used to create a steeper slope.

Design Flow. Because structure design is based on flood velocities and depths, it is necessary to select one or more design flows to analyze the hydraulics of the reach and find the values of the necessary variables. A range of flows, up to and including the 100-year event, should be examined depending on the site characteristics, project complexity and its associated risks. Of particular interest is the bankfull or overtopping event for the structure in question; this event generates the greatest velocities and tractive forces.

Design Velocities. Local water velocities (i.e., velocities at or near the area of erosion), not average channel velocities, should be used for design. Local velocities along the outside of bends,

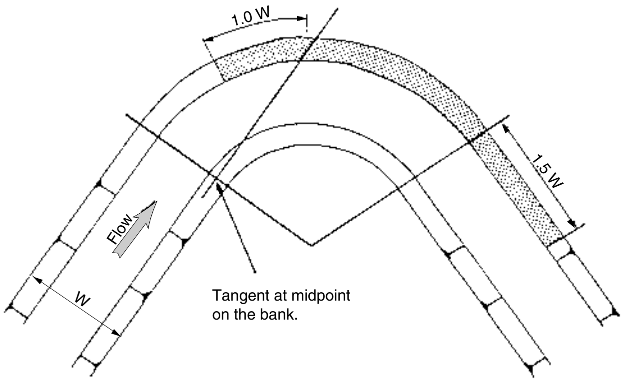
Figure 7.2 Setback levee.



for example, can be as much as 50 percent greater than the average velocity at that cross-section (Maynord et al. 1989). Analytical methods for estimating velocities in curved channels and/or engineering judgments are used for predicting the effects of the outside of bends and other hydraulic factors on the local velocities. Occasionally, the designer will be faced with placing protection along a straight channel reach. In these cases, the local velocity is often less than the average velocity. Methods for estimating local velocities are discussed further in Appendix C.

Extent of Protection. Many designers mistakenly extend erosion protection too far upstream and not far enough downstream, particularly for structures on the outer banks of bends (Figure 7.3). The highest velocities generally occur at the downstream end of the bend, and on the outer bank of the straight section immediately downstream. Often, the erosion potential does not decrease appreciably until the channel straightens and the thalweg crosses over to the opposite bank for the next bend. The downstream movement of meander bends should also be considered. If not properly oriented, the structure can deflect flows and create erosion problems on the opposite bank.

Figure 7.3 A schematic of the minimum extent of protection required at a channel bend. (Adapted from Lagasse et al. 1991.)



Tie In. It is important that the end points of the facility be tied into a stable bank area. Some bank protection measures such as riprap structures create "hardpoints" that can cause erosion at more susceptible locations up- or downstream of the project area. The upstream end of the facility in particular must withstand the greatest forces. In general, structures should be continued to an area of reduced velocity. If not, erosion may remove bank materials from behind the face of the structure. This greatly weakens the facility and can cause possible failure.

Another method of tieing in is to construct a rock deflector at each end of the facility. This deflector acts as a hardpoint that deflects flows away from more vulnerable point along the bank. This is particularly valuable at the downstream end of structures such as rock revetments.

7.2.2 ROCK PROTECTION METHODS

Rock protection methods include toe keys, deflectors, and revetments. These methods are commonly used where bank materials are weak and water velocities are high.

Rock Toe Key

At sites where toe erosion has been identified as the mode of bank failure, stabilization structures should be keyed into the channel bed at the bank toe. While this may be obvious where toe erosion is the major problem, all alluvial streams scour during flood events unless the bed is armored with large material. If the stream is undergoing bed erosion, whether by general degradation or headcutting, structures must be protected against undercutting.

Rivers with highly mobile beds (i.e., large fluctuations in scour depth) may require deep toe key placement. Recent feasibility studies on the Tolt River and South Fork Snoqualmie Rivers, for example, included a recommendation to place the toe key a minimum of three feet below the lowest recorded thalweg elevation (Shannon and Wilson 1993a; 1993b). Both of these preliminary recommendations require detailed scour analyses to develop the final toe key design.

For large river environments, Lagasse et al. (1991) recommends placing the riprap a minimum of five feet below the original streambed elevation. Alternatively, the potential bed scour can be estimated, and the toe then placed deeper than the predicted scour depth. Methods for accurately predicting scour have been developed by Richardson, Harrison and Davis (1991) and Richardson, Simons and Julien (1990). Although the methodology specifically addresses scour in the vicinity of road crossings, it is useful in any evaluation of bed scour.

Toe key dimensions depend on stream characteristics, level of protection, and type of structure. The major consideration in designing a toe key is the proper sizing of the rock. The rock must be large enough to remain stable under the flow depths and velocities to which it will be exposed. Typically, rocks will need to have a minimum dimension of two feet or a minimum weight of at least five hundred pounds. Over-sizing the rock should generally be avoided because of increased cost and difficulty of placement.

The toe key can be difficult to construct in rivers with high banks. In these situations, it is extremely difficult to reach down from the top of the bank with a dragline to key rock in at the toe. An alternative is to design a bench at ordinary high water that can be used as a construction platform. The bench can be left as a permanent feature which then allows the upper bank revetment to be set back from the main channel of the river.

The width of the toe key is not as critical as its depth. For riprap revetments, the minimum width of the key should be 1.5 to 2 times the thickness of the riprap blanket at the base of the slope. If used with cribwalls and vegetated geogrids, the toe need not extend beyond a line formed by extending the slope angle of the structure to the maximum key depth.

Quarried stone is recommended because angular rock tends to interlock, which makes it more stable. Using rounded stream rock is discouraged because it is less stable. In stream areas where the rock has formed an armor layer, its removal by mining operations may cause local scour problems. Irregular rocks should be placed with the long axis parallel to the flow. Only hard rocks, such as granite or other volcanic rock that will not erode rapidly, should be used.

Large rock may be added to the toe for habitat purposes if it does not create currents that cause erosion problems. Rocks create habitat by providing refuge from high flow velocities (a form of cover) and creating scour holes. Rocks are usually placed within the zone of highest flow velocities and can be incorporated into the toe of a protected slope. Rocks used in this fashion are intended to create velocity refuges, rather than scour holes. Habitat elements are discussed in greater detail in Section 7.2.5.

As an alternative to using large rock, it is possible to use smaller stone wrapped in a natural or synthetic geotextile material. Because abrasive sediments and debris will wear, snag and tear these fabrics with time, high flows may remove this smaller rock. This can potentially undermine the structure and cause it to fail. The geogrid material should have high tensile strength and resist corrosion and abrasion. The diameter of the rock fill used in the wrap must be greater than the size of the grid openings but should not exceed six to eight inches. If larger stone is used, there should be sufficient small rock to fill voids between the large stones so that the fill cannot shift and allow the structure to settle over time.

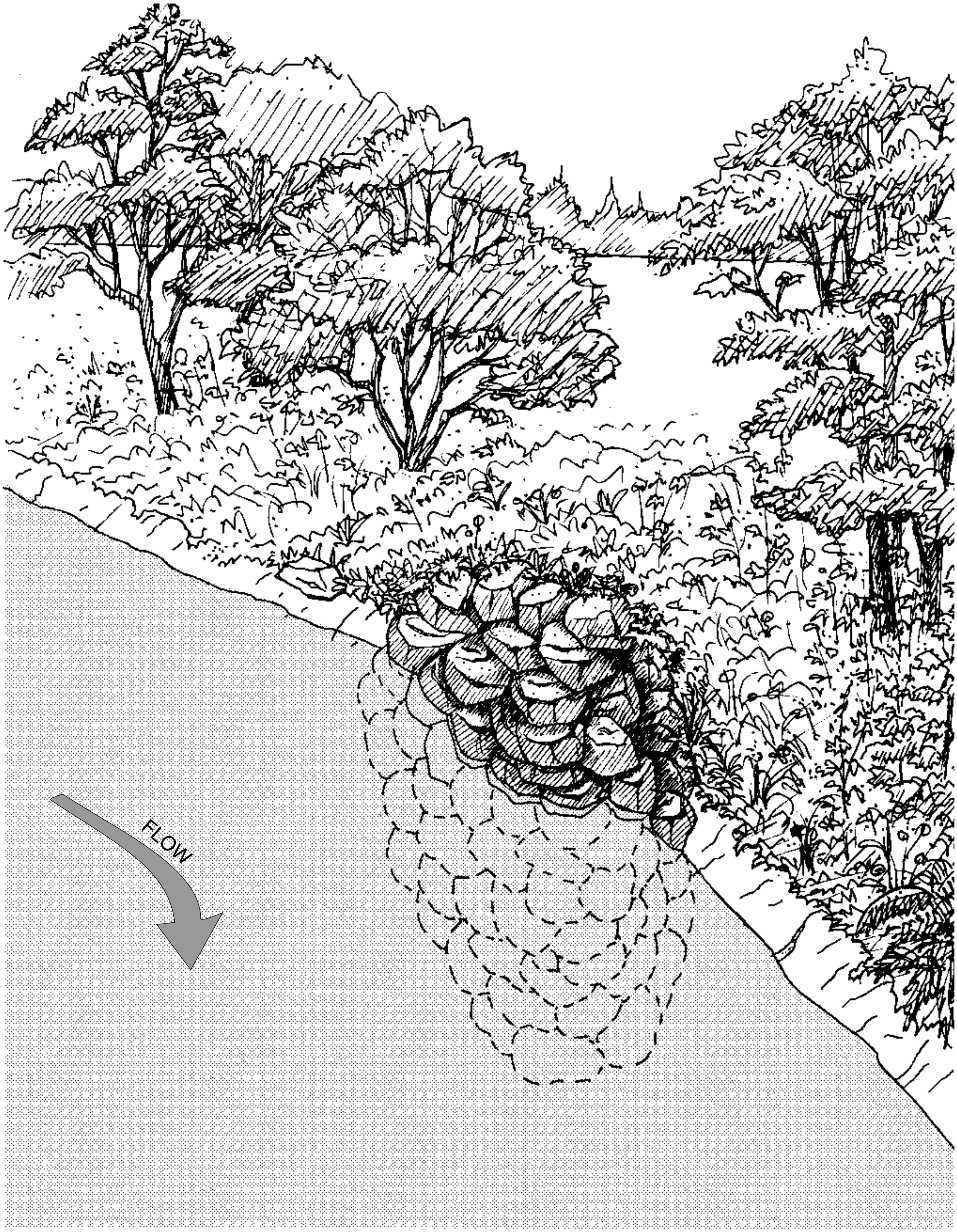
Deflectors

Deflectors are structures that are attached to one bank and project into the flow (Figures 7.4 and 7.5). Commonly referred to as spurs or spur dikes, deflectors protect erodible banks by directing the flow toward the middle of the channel. They are useful in reducing meander migration and water velocities near the bank. The scour holes that form around deflectors can provide rearing pools and cover for fish.

The design variables most used for deflector design are: orientation angle, effective length, crest height, placement site, construction material, spacing between multiple deflectors, and deflector construction materials. The following is a list of recommendations and options, not strict rules for designing deflectors (Conner 1991):

Orientation Angle. Deflectors oriented upstream create larger and deeper scour holes than

Figure 7.4 Downstream oriented rock deflector keyed into a streambank.



perpendicular or downstream oriented deflectors (Klingeman et al. 1984). Deflectors oriented upstream may also be the most unstable. The eddies that form on the upstream face of the deflector may scour a longitudinal hole along the bed, undermining the structure and causing it to roll forward (Owusu and Klingeman 1984). The eddy formed in the pocket between the upstream oriented deflector and the bank protect the bank from higher velocities. If the eddy velocity is sufficient to transport local bank materials, it will scour the bank and undermine the structure (Copeland 1983).

Deflectors oriented downstream direct the flow away from the bank along the deflector (Klingeman et al. 1984). Because the flow deflection angle approximates the orientation angle, the designer can predict where the flow may impinge on the opposite bank (Klingeman et al. 1984; Reeves and Roelofs 1982). These areas may be protected by riprap, vegetation, or by placing another deflector to intercept the flow. The downstream orientation causes less flow deflection, and therefore, little or no scour of the opposite bank (Owusu and Klingeman 1984).

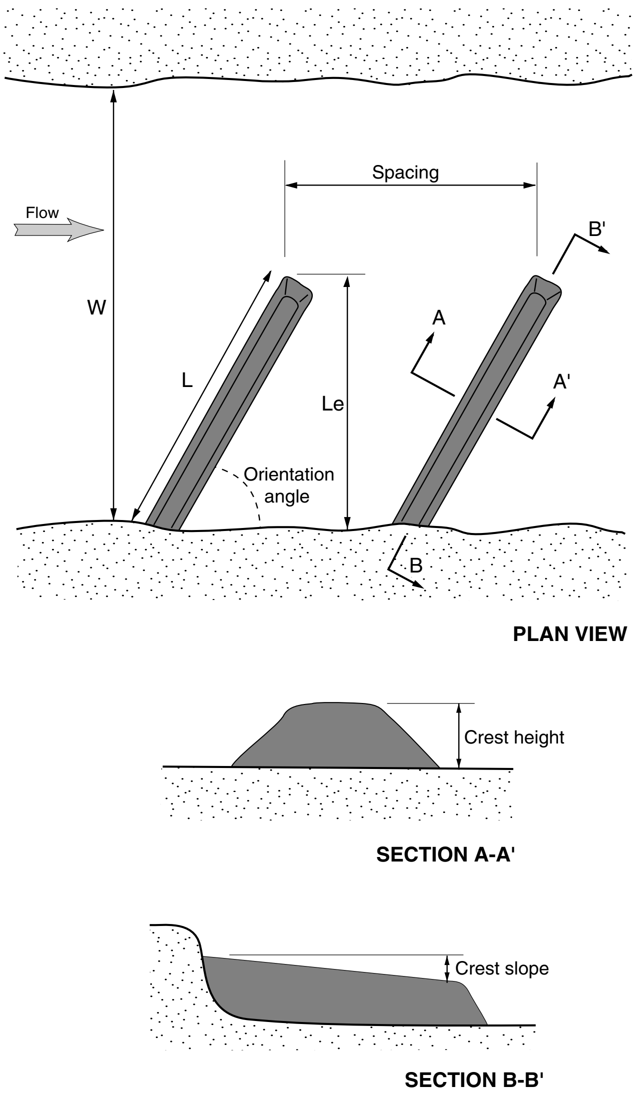
A downstream orientation is recommended at sites where bed and bank stability may be a problem. Additionally, debris and ice are less likely to accumulate on downstream oriented deflectors (Klingeman et al. 1984). For these reasons, downstream orientation of these structures is generally recommended (Federal Highway Administration 1979; British Columbia Ministry of the Environment 1980; Seehorn 1985; Wesche 1985).

Perpendicular deflectors may be the most cost-effective bank protection because the length of bank protected is directly correlated with the effective deflector length (Copeland 1983). Because perpendicular deflectors intercept flow at an abrupt angle, they may also be more inclined to fail. Special care should be taken in the design stage to prevent failure of single perpendicular deflectors. The perpendicular design is often used in combination with multiple deflectors to protect a length of bank.

Effective Length. The greater the channel constriction caused by the deflector, the greater the velocity at the tip of the deflector and the greater the scouring potential of the flow. The channel constriction or solidity is represented by the effective length of the deflector (Le) compared with the channel width (W).

The deflector must be long enough to deflect the flow away from the length of bank to be protected, unless riprap or another secondary bank protection is used. Several shorter deflectors may also be used to protect the same length of streambank as one long deflector. Miller and Kerr (1984) found that a deflector could protect the downstream bank for 2 to 5.5 times its effective length, depending on the expansion angle of the flow. Severe channel constriction may cause a

Figure 7.5 **Schematic diagram of a deflector. (Adapted from Conner 1991.)**



sharper expansion angle, and thus decrease the length of bank protected per length of deflector (Klingeman et al. 1984). Miller and Kerr (1984) found in flume studies that the optimum effective length for bank protection was 0.2 of the flume width.

Recommendations for effective length in the literature range from Le/W of 0.25 to 0.8 (Seehorn 1985; Wesche 1985; Crispen 1988). Although these authors claim that deflectors may block as much as 60 to 80 percent of the flow area, these deflectors would likely create adverse effects and fail. Thus, deflectors that block significant portion of the flow area are rarely practical.

Deflectors can create effective fish habitat by producing scour holes. To create scour holes that benefit fish, deflectors must be long enough to intercept a substantial portion of the flow. Garde et al. (1961) found that in straight reaches, the depth of scour was 0.2 to 0.5 the effective length of the deflector. Lagasse et al. (1991) provide criteria for predicting scour depth at deflectors.

Unless desired, the deflector should not be so long that it directs the flow into an erodible opposite bank. The opposite bank may be protected or a deflector may be placed downstream on the opposite bank to intercept the flow. If the deflector is submerged at high flows, it may extend across a greater portion of the channel without causing erosion of the opposite bank.

Crest Height. If the risk of flood damage to adjacent roads is of concern, deflectors should be submerged at high flows so that they do not catch debris (Federal Highway Administration 1979; British Columbia Ministry of the Environment 1980). Seehorn (1985) suggests that this condition will be met if the deflector is no more than 6 to 18 inches above average summer low flow level. Deflectors should be no higher than the top of bank and slope downward to the tip to prevent undermining (Franco 1967). Deflectors with a sloping crest have to be longer than level crested deflectors to achieve the same amount of bank protection and bed scour (Klingeman et al. 1984). To maximize deposition, a series of deflectors can be arranged so that the crest of each deflector is lower than the one just upstream (Franco 1967).

Deflectors that are designed to be overtopped at high flows should be shaped so that the flow is not directed into erodible banks at high flows (Federal Highway Administration 1979). An upstream oriented deflector or triangular shaped deflector will shunt high flows toward mid-channel and cause deposition along the bank.

Spacing of Multiple Deflectors. A series of deflectors can be used to protect a length of eroding bank. The goal is to redirect the thalweg away from the eroding bank. The deflectors should be spaced so that the flow expanding downstream of one deflector is intercepted by the next and redirected toward the opposite bank. To determine deflector spacing on the outside bank of bends, Miller and Kerr (1984) suggest projecting the tangent of the thalweg from the tip of the upstream deflector to the bank downstream. The downstream deflector should be designed to intercept this flow. They suggest that the spacing be reduced by 20 percent on sharp bends. The thalweg of the stream straightens at high flows and thus will impinge on the bank in the downstream portion of a concave bend (Miller and Kerr 1984). Deflectors should therefore be placed closer together in the downstream portion of a concave bend to protect the bank at high flows (Reeves and Roelofs 1982).

For the most effective bank protection, deflectors should be spaced close enough so that flow will circulate between the deflectors, creating a buffer zone of eddies that protect the bank from higher velocity flow (Copeland 1983). Klingeman et al. (1984) found that the optimum spacing for developing this protective eddy system varies between three and four times the effective deflector length and decreases as deflector length increases beyond 0.2 of the channel width. Spacing deflectors too close reduces sediment deposition between structures (Crispen 1988).

Arrangements of multiple deflectors for various purposes have been recommended in the literature. Spacing deflectors such that their flow patterns interact creates more scour and diversity of habitat than they do individually (Heiner 1989). Pairing deflectors opposite each other centers the thalweg and creates a long, deep plunge pool (Federal Highway Administration 1979). Alternating deflectors can be used to help re-establish or create a meander pattern (Wesche 1985; Crispen 1988).

Deflector Construction Materials. The most common construction materials used for deflectors are rocks and logs. Rock deflectors can be constructed of two to three rows of interlocking rocks extending out into the flow (Federal Highway Administration 1979; British Columbia Ministry of the Environment 1980). The largest rock should be placed at the tip of the deflector as this is the zone where maximum velocity occurs. Rock size can be less than that recommended for fishrocks as discussed in Section 7.2.5.

Blunt, wedge-shaped rock deflectors should be used for bank stabilization. These create less flow disturbance and therefore are less likely to cause scouring of either the bed or banks. Single large boulders, when properly placed, may act as flow deflectors (Oregon Chapter of the American Fisheries Society 1988).

Rock deflectors should be embedded in the bed and banks to prevent undermining. The depth that the boulders should be embedded depends upon how much scour is expected around the base and root of the structure. Orsborn and Bumstead (1986) recommended rock deflectors be embedded for a distance equal to the height of the deflector.

Rock Revetments

A carefully placed layer of angular rock, generally known as riprap, is a common and effective method of bank protection used on levees and revetments. While rock offers some resistance against mass-movement, its primary purpose is to prevent loss of bank material by fluvial erosion. Because the system is flexible, riprap can settle and conform to the final streambed contour if scour occurs. Over time, vegetation may become established in riprap above the waterline.

Revetments have typically been constructed from hand-placed, dumped, or derrick-placed rock. Many types of structural facings have been used. These include: riprap; gabion mattresses; rubber tire networks; articulated, precast concrete blocks; and cellular grids. Because of environmental and aesthetic concerns, most of these methods have not gained acceptance in King County. Because the most common revetment in King County is rock, the remainder of this discussion will focus on this material.

Riprap revetments are particularly effective in the following situations: 1) sharp bends; 2) constrictions, such as bridges, where velocities increase; 3) along the opposite bank at the confluence of two rivers; and 4) on rivers where debris damage may occur.

Limitations. Rock revetments have several limitations. These include environmental impacts such as the destruction of fish and wildlife habitat, encroachment into the floodplain, and loss of aesthetic values. Rock should not be prescribed without first carefully considering other alternatives. Even where rock is absolutely necessary, an attempt should be made to incorporate vegetation; the structure should be sufficiently set back from the channel to enhance rather than degrade riparian environments and instream habitat.

Other factors that may limit the use of rock include the availability of suitable-size rocks, the difficulty and expense of quarrying, transporting, and placing stone, and the large amount of material needed for deeper streams. While small riprap may be hand-placed, most is end-dumped or placed by derrick crane or other large equipment.

Gradation. For riprap to function properly, it is essential that it be well-graded. A reasonable gradation will allow the various rock sizes to interlock and minimize voids in the structure. It is essential that there be no significant gaps (missing sizes) in the gradation. Gaps in the gradation increase the chance of structural failure if high flows remove smaller rock particles, causing larger particles to settle. Wittler and Abt (1990) found that a relatively uniform gradation can withstand greater erosive forces. Failure of these rock facilities, when it occurs, can be more rapid than those facilities having a broader gradation.

Because many standards have been developed, the riprap gradations--along with the median stone size--should be specified in the design plans. The standard gradations generally used in King County have been those developed by the Washington State Department of Transportation

(DOT). These range in size from quarry spalls, through light loose riprap, to heavy loose riprap. The specific sizes of this material, and the methods for computing the size appropriate for a specific site, are described in Appendix C.

Filter Layer. Most riprap is placed on a filter blanket of smaller sized, graded material. A proper filter layer prevents the loss of finer soil particles of the bank through the interstices of the riprap layer. If these finer soil particles are lost, slumping and failure may occur. The area to be covered with a filter blanket should be reasonably smooth. An even thickness of filter material should be placed on the prepared surface. Riprap should be placed carefully to ensure that the blanket is not ruptured or displaced. For most of the rivers in King County, a filter layer of gravels or quarry spalls is recommended. Relationships between sizes of riprap and gradations of adjacent layers have been developed to size the individual rocks in the filter layer. These relationships are discussed in detail in Appendix C.

Geotextile fabrics have sometimes been used to create this filter. It can be more difficult, however, to key a large rock blanket into fabric than into a blanket of smaller rock. Fabric filters are most useful when the banks consist of fine-grained alluvium. Banks with extremely fine-grained soils such as silt or clay may require both a geotextile fabric and a rock filter.

Bank Slope. Because steep slopes lessen the stability of the total structure, rock should not be placed on slopes steeper than 2H:1V. Steeper slopes may require a retaining wall or other structure. Maynord et al. (1989) state that stability tests have shown that slope has small effect on riprap stability when side slopes are flatter than 2H:1V. Because high flows can saturate river banks (creating failure in the underlying material), it is vital that the revetment face slope does not exceed the angle of repose of the underlying layer.

Because riprap is usually installed at sites of severe erosion where the existing side slopes are often steeper than 2H:1V, substantial site grading is often required. When needed, the bank slopes should be laid back away from the channel where possible to obtain the appropriate slope angle. Encroachment into the channel is not recommended. Encroachment that can not be avoided will require an exemption from the floodplain regulations contained in the King County Sensitive Area Ordinance. Grading of the slopes may increase right-of-way requirements. It is also extremely difficult in situations where existing buildings, other structures, or large mature, vegetation are located near the existing top of bank.

Shape of Rock. As noted in the toe key discussion earlier, angular rock is preferred to rounded rock because the stones fit together to provide a more solid blanket. Because this strengthens the revetment so that it acts like one structure rather than a collection of independent stones, it raises the threshold velocity for incipient motion and subsequent failure. Quarry rock is preferred to natural river rock as it is generally angular; river rock is usually rounded and unacceptable as riprap. While the rock should be angular, ideally it should be as nearly rectangular as possible. The ratio of the longest to the shortest dimension should be no more than 3.5:1 (USACOE 1991).

Toe key. As discussed earlier, lack of a sufficient toe key is a common cause of bank and riprap failures. Because tractive forces are greatest in this zone, a well-constructed toe is essential. If the toe is not sufficiently deep and effectively keyed into the streambed below the anticipated scour line, the entire structure may be undermined.

Height of Riprap Face. In determining the height of the riprap face, a factor of safety (related to water surface elevation) should be incorporated into the design. For installations that are comprised of riprap only (as opposed to vegetative or integrated methods), Lagasse et al. (1991) recommends extending the riprap to a minimum of two feet above the design water surface elevation. Riprap should extend up the bank far enough to provide adequate protection against scour by debris, flowing water, or wave action.

In situations where the natural channel has been constricted, the designer will often find that the capacity of the channel is insufficient to convey the design storm. In these cases, either rock protection should be provided to the top of the bank or construction a setback levee should be considered. If sufficient space is available, a setback levee is the preferred alternative.

When flood containment is a project objective, the design water surface elevation should be adjusted to account for the superelevation resulting from centrifugal forces at bends. Chow (1959) provides methods for computing superelevation. Freeboard should be added to this superelevation estimate. The Corps and FEMA both may require three feet of freeboard above the 100-year water surface as a factor of safety for levees (see Section 5.8 for further discussion).

Vegetation. Vegetation on the face of the riprap structure can be an important component of bank stability. In the past, maintenance of riprap structures often involved periodic removal of all vegetation under the assumption that this would improve access and visibility for inspecting facilities, and that large vegetation, if uprooted, could severely damage the riprap face.

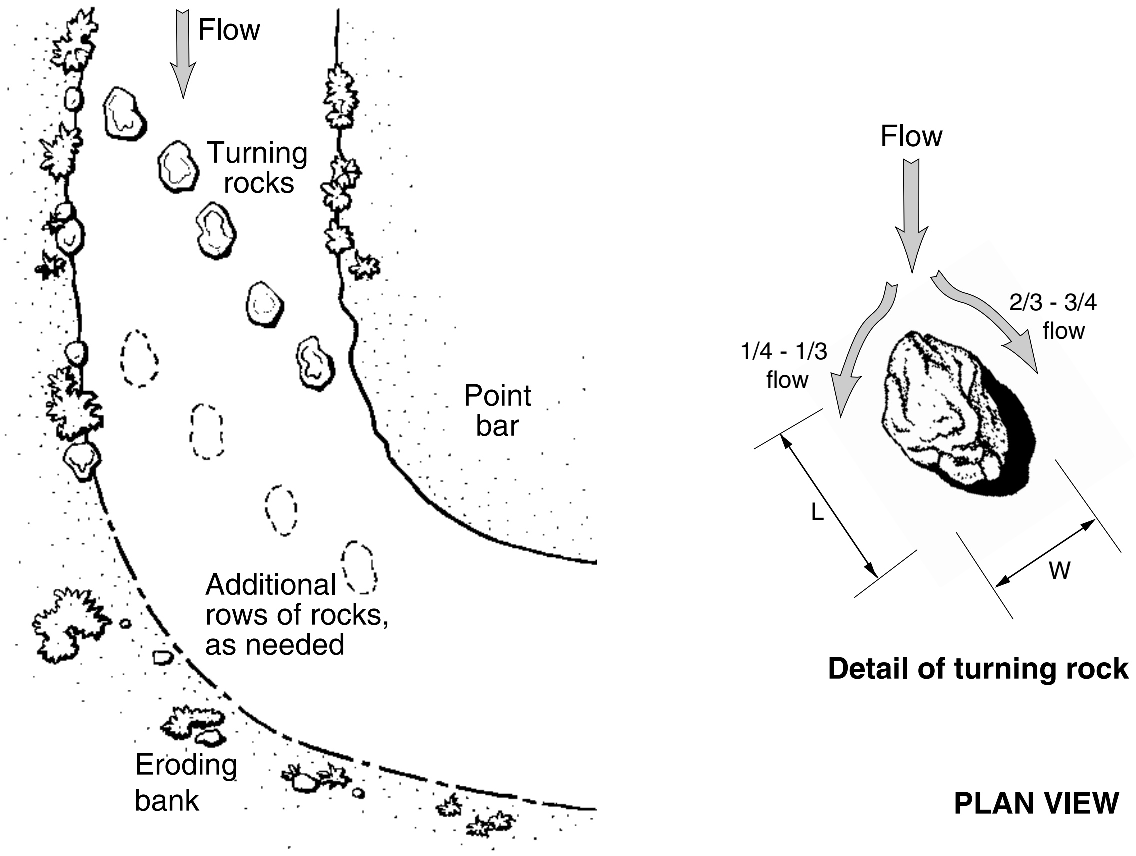
Recently, regulatory agencies, such as the Washington Departments of Ecology, Fisheries, and Wildlife, have required the incorporation of vegetation in levee and revetment faces. For this to be successful, the vegetation must come into contact with the soil underneath or within the riprap armor. Depending on the season, irrigation may also be necessary.

Other Rock Structures

Many other types of rock structures have been used successfully for bank protection. These include turning rocks, tie-backs, and rock-fill trenches. Because a detailed discussion of these structures is beyond the scope of this document, they will be described only in general terms. The reader is referred to Orsborn and Bumstead (1986) and Lagasse et al. (1991) for further information.

Turning Rocks. Turning rocks are rows of boulders placed in a bend starting at the upstream outside bank and angled toward the inside bank to reduce erosion (Figure 7.6). Turning rocks reduce

Figure 7.6 Turning rocks used to reduce erosion on the outside of a bend.



the spiral currents that erode the outside bank of a bend. They also help dissipate energy to reduce stream power locally and provide cover for fish.

Turning rocks are placed in a downstream diagonal across the stream to deflect the flow. Each successive rock divides the flow and deflects the majority in the desired direction. The next rock downstream is placed to intercept the deflected flow from the upstream rock and so on. The longest axis of each rock should be positioned at a slight angle to the flow (Orsborn and Bumstead 1986).

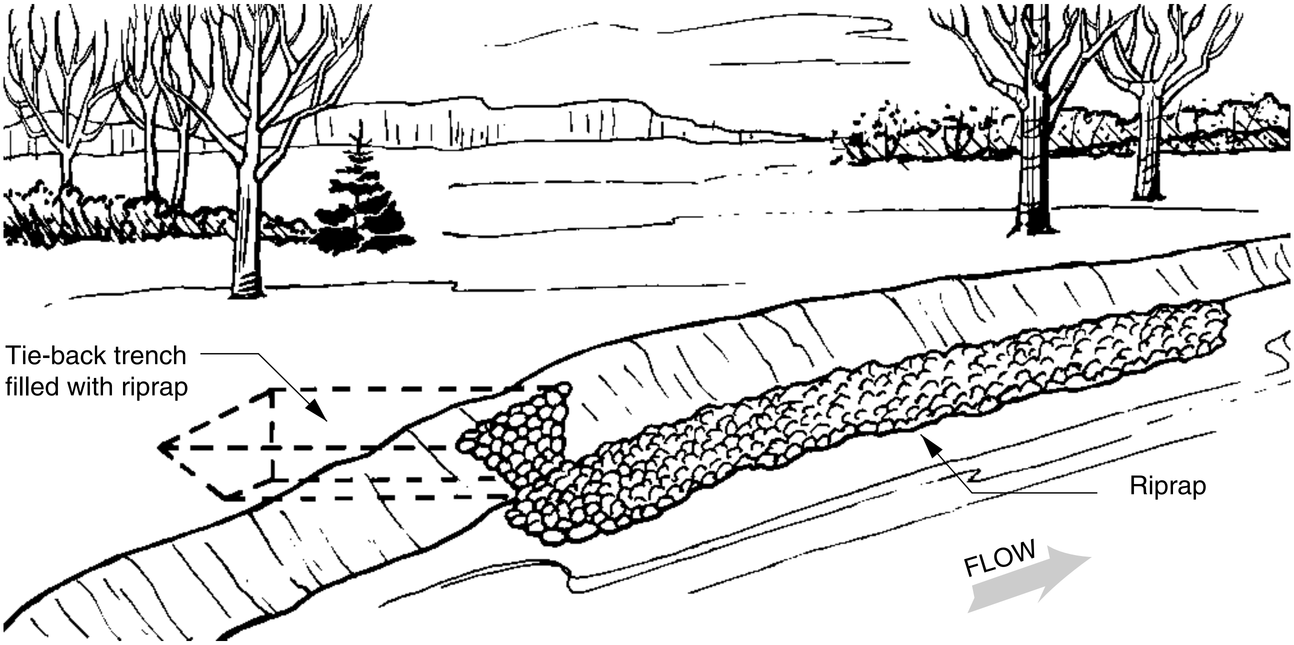
Turning rocks can be used to direct the flow away from an unstable bank or to direct the thalweg down a selected part of the channel. Several rows may be needed depending on the length and radius of the curve (Orsborn and Bumstead 1986). Because turning rocks may not be adequate to turn the flow by themselves, especially in deep streams or rivers, other structures such as deflectors may be needed to provide adequate protection from erosion.

Tie-Backs. Tie-backs are individual sections of riprap or other structural protection placed perpendicular into an eroding bank to prevent flanking by floodwaters (Figure 7.7) . Depending on the design, they are placed against the bank, and either lay flush against it or protrude slightly into the stream channel. Tie-backs protruding into the channel create hardpoints that provide some energy dissipation. In this way, protection from erosion is provided without hardening the entire streambank. Because much of the existing bank line is left undisturbed, a favorable environment for the establishment of native vegetation remains. Tie-back revetments are created by connecting the hardpoints with a rock revetment or toe key.

These structures are not effective for extremely high velocity flows. They are most useful in relatively straight reaches where the primary erosion threat is a meandering thalweg. On the outside of bends, a revetment or a series of rock deflectors is usually more appropriate.

Rock-filled Trenches. A rock-filled trench is placed parallel to the bankline such that the rock can fill scour holes and/or scalloped banks as erosion progresses. The trench is dug behind the bank of the channel and filled in with riprap. The trench is then covered with a layer of soil and replanted. This method does not modify the channel and yet provided the riprap trench will halt erosion if it occurs. This method provides additional protection when greater security is required.

Figure 7.7 Tie-back trench and revetment to prevent flanking. (Adapted from Richardson et al. 1991.)



Another application of a rock-filled trench is to construct it within the channel itself, immediately adjacent to the toe of the bank. As bed scour occurs, the rock settles in to the degrading toe. Protection from undermining is provided as long as the eventual depth of scour does not exceed the capacity of the quantity of rock used. In rapidly eroding river environments (outside of bends, etc.), a keyed-in toe is preferable to a rock-filled trench type.

7.2.3 VEGETATIVE METHODS

Vegetative methods include herbaceous ground covers, rooted stock, live stakes, fascines, brush mattresses, and brush layers. While the root systems of these components increase the "structural integrity" of a bank with time, their initial value is in protecting the bank surface. These methods usually can be installed with minimal instream disturbance.

Evaluation factors for selecting the appropriate plant species and method of application include slope, aspect, soil characteristics, drainage, elevation and tolerance of the plant species to inundation. Much of this is discussed in Chapter 6. Ideally, the selection of vegetation should be restricted to native species that are suited to the site conditions.

Plants should be chosen based on their adaptability and tolerance to soil moisture levels, especially on very wet or very droughty sites. The plant associations in Table 6.4 include many species suited to particular conditions. Planting plans should be designed using subsets of this list or other species as appropriate, depending on site-specific conditions and stock availability.

Herbaceous Ground Cover

Herbaceous ground covers include grasses and other non-woody vegetation. Although they lack some benefits of woody vegetation (e.g. cover for fish), herbaceous vegetation is useful in some situations. Ground cover provides temporary erosion control until woody vegetation becomes established or where cover on bare ground or soil improvement is desired. Sod-forming grasses and legumes, especially if left unmowed, can protect banks of small streams where flow velocities are low.

Grass species recommended for western Washington streambanks are listed in Table 7.1. Although individual species are listed in this table, a mixture of species may be more successful and desirable than a monoculture. Erosion control seed mixtures are commercially available, and can be tailored for site conditions. Seed mixtures should include annual and perennial species and species that will enrich the soil (e.g., legumes). The need for fertilizers should be evaluated and appropriate kinds and amounts applied. Local Soil Conservation Service personnel are a valuable source of information about specific plant requirements. Wasser (1982) provides an excellent summary of grasses, forbs, shrubs, and trees useful for revegetation projects in western states.

The use of grass and forb turfs to protect streambanks is constrained by velocities of design flows. At present, information on design velocities for native grasses is not readily available. Examples of maximum allowable design velocities for other selected grasses are listed in Table 7.2.

While unmowed turf also can provide habitat for small mammals and ground dwelling birds, thick turf or grasses may hinder the establishment of woody vegetation by competing for water and nutrients. Thick turf may also encourage populations of small rodents that girdle trees and shrubs when feeding on bark.

Rooted Stock

Rooted stock is any tree, woody shrub, or herbaceous plant with established roots. This includes rooted cuttings, balled and burlapped, bare-root, and containerized plants. This material is used either alone or with other methods to provide

Table 7.1 **Grasses and ground covers recommended for use on and adjacent to channel banks in western Washington. (Adapted from SCS 1986.)**

	Recommended Seeding Rates for Given Site Conditions[1]			
Species	Shallow or Droughty	Dryland	Irrigated or Sub-irrigate[2]	Palustrine orWetland
tall fescue *Festuca arundinacea*	18	18	18	
creeping red fescue *F. rubra*	8	8	8	
sheep fescue *F. ovina*	5	5		
bentgrass *Agrostis spp.*			1	1
perennial ryegrass *Lolium perenne*		15	15	
tiny white clover *Melilotus alba*	10-15			
big trefoil *Lotus crassifolius*			4	4
white or Dutch clover *Trifolium repens*		2	2	
red clover *T. pratense*		4	4	
sicklekeeled lupine *Lupinus albicaulis*	10	10	10	

1. Minimum seeding rates in lbs/acre.

2. Includes sites receiving extra moisture from runoff, snowmelt, stream water, etc.

Table 7.2 **Example maximum allowable design velocities for channels vegetated with selected grasses. (From Simons, Li, and Associates 1982.)**

	PERMISSIBLE VELOCITY (fps)		
Type of Grass	Slope Range (%)	Erosion Resistant Soils	Easily Eroded Soils
Bermuda grass *Cynodon spp.*	0-5	8	6
	5-10	7	5
	over 10	6	4
Buffalo grass *Buchloe spp.*	0-5	7	5
Smooth brome *Bromus inermis*	5-10	6	4
Blue grama grass *Bouteloua gracilis*	over 10	5	3
Alfalfa *Medicago sativa*	0-5	3.5	2.5

leafy cover and root strength because it sends roots into the surrounding soil in weeks rather than months that cuttings may take. It may be placed anywhere on the bank where it will not be removed by erosive flows.

Rooted stock should be used for planting during the growing season when unrooted cuttings may not survive. It is also useful where soils are droughty, nutrient poor, where rooting of cuttings is doubtful or when cuttings of desired species are unavailable. Species that do not root readily from cuttings such as conifers can also be incorporated into designs in this manner. Rooted plants may be added where understory vegetation already exists and larger shade-providing plants are desired. Rooted stock provides immediate vegetative cover and habitat improvement.

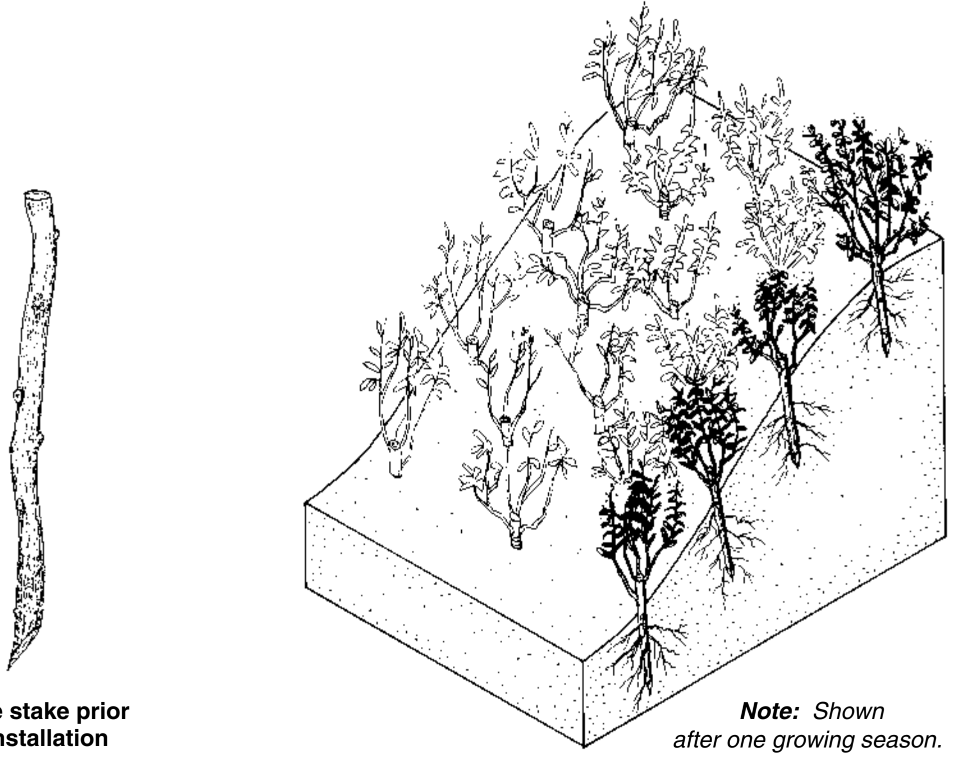
Spacing of rooted stock is dependent on the eventual size of selected species. Depending on the root distribution needed, plants may be spread evenly across the site for uniform cover or clumped for a more natural appearance. The plants vary in size from small (inches) to large (10 or 12 feet tall). Containerized stock has a relatively high cost per plant. Even with established roots, rooted stock at some sites may require irrigation for one or more seasons.

Live Stakes and Slips

A quick and effective means of securing a vegetative cover for control of soil erosion and shallow sliding is planting unrooted cuttings. Live stakes are woody plant cuttings that can root, and are large and long enough to be tamped into the ground as stakes (Figure 7.8). Live stakes are generally cut from wood that is two or more years old. Slips are similar to live stakes, but smaller in size. Slips, which are cut from first or second year wood that is still soft and flexible, are not strong enough to act as anchors.

Cuttings from plant species that root easily will grow if planted under favorable conditions. It is well known, for example, that most willows, many poplars, and cottonwoods, readily grow from cuttings set in moist soil (Gray and Leiser 1982). Even in very unfavorable conditions (e.g., deep shade), live stakes will often grow vigorously for a few years before they die out. During

Figure 7.8 Live stakes.



Live stake prior to installation

Note: *Shown after one growing season.*

this time, they will stabilize and modify the soil, and serve as pioneer plants until other plants can become established. Live stakes are effective in camouflaging an open area after one or two growing seasons. Over time, the cover provided by live staking creates riparian and wildlife habitat.

Live stakes are useful alone or when used with straw, jute mesh, and coir (a coconut fiber mesh) for providing surface protection and in controlling small rills and gullies. They are also effective when construction time is limited, an inexpensive method is necessary, the problem is very simple, or when work in the channel is not allowed or desirable. Slips are useful for small projects with similar characteristics and sites with soft, moist soil. While live stakes and slips require moist soil to root, excessive water will result in rotting.

The density of the installation ranges from two to four live stakes per square yard. Live stakes should be spaced approximately every two feet in a random to triangular pattern. For slips, higher density (about 12 cuttings per square yard) at one foot spacing is recommended. Live staking requires a moderate to large volume of live plant material. Live stakes can be interplanted with rooted stock.

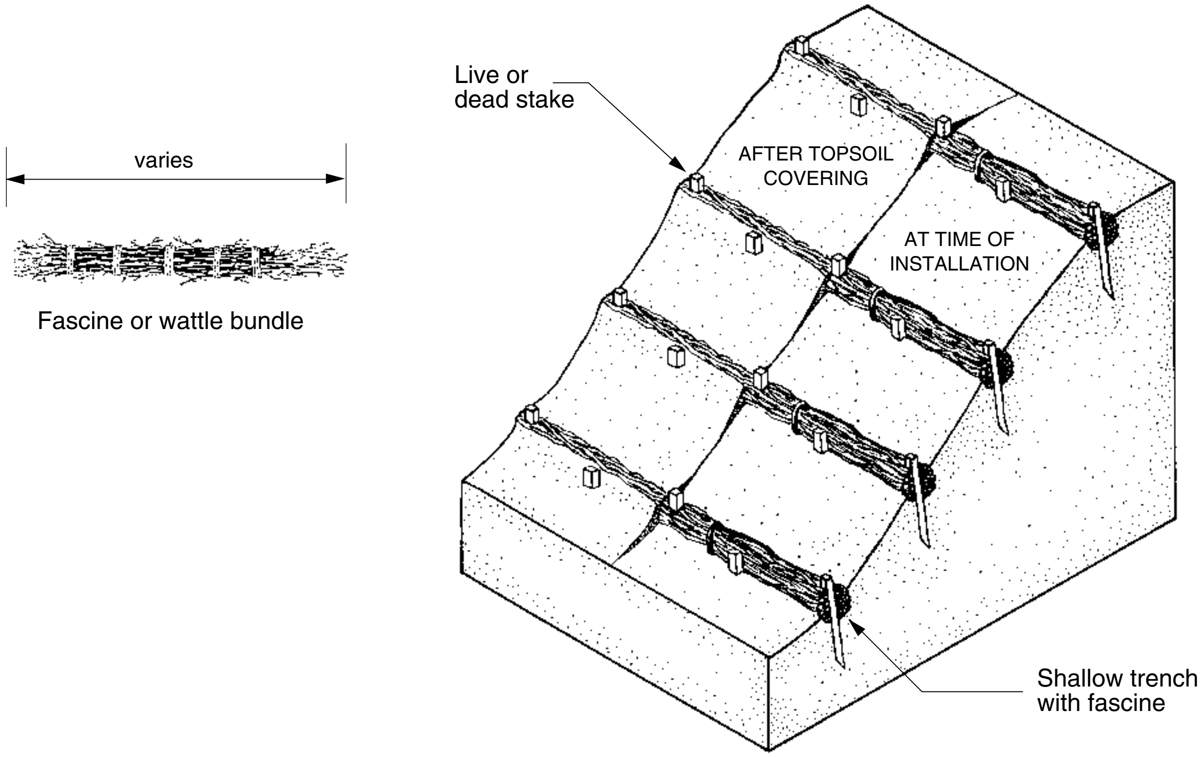
Fascines

Fascines are sausage-like bundles of long, live cuttings tied together and secured to the bank with live and dead stakes (Figure 7.9). They are placed on the bank face in shallow trenches and lightly covered with soil. These are also called wattles or contour wattles.

Fascines are useful for areas of general scour where the banks can be sloped back. They work particularly well in straight sections where flow velocities are low. Fascines offer inexpensive and immediate protection from erosion, especially from overland flows moving downslope. They usually do not require work in the channel.

Fascines work well to reduce erosion on shallow gully sites and help in controlling surface erosion by reducing the slope into a series of smaller slopes. They are an effective stabilization technique once installed and even more so when roots become established. Fascines help hold soil

Figure 7.9 Fascines.



on streambank faces by creating mini-dam structures or terraces. The erosion control capabilities of this system can be enhanced by using straw, jute or coir mesh to cover surface areas between fascines. These materials provide stable growing surfaces that help the invasion of surrounding riparian vegetation.

The fascines should be spaced three to five feet apart on contour, parallel to the stream (Schiechtl 1980). Installation should begin at the wetted edge of OHW and continue up slope.

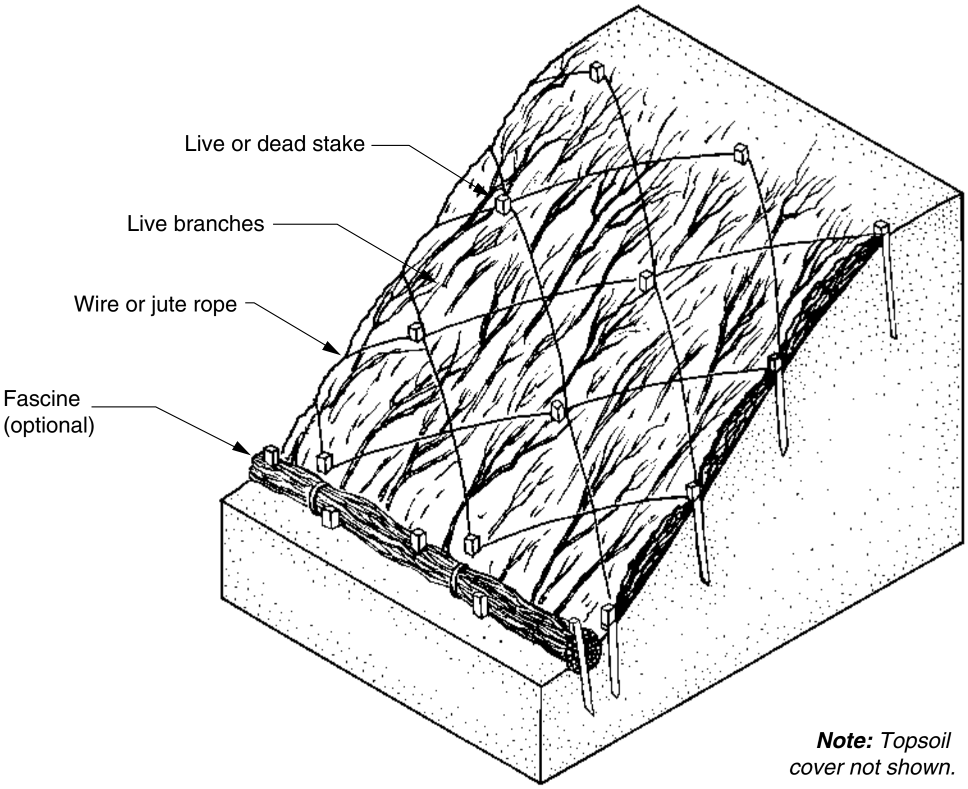
Brush Mattresses

A brush mattress is a combination of units that cover the streambank to provide immediate protection. The units used in this method are live and dead stakes, fascines, and a mattress-like branch cover (Figure 7.10).

Used alone, brush mattresses provide some bank protection and erosion control; they can resist temporary inundation, but not undercutting (Gray and Leiser 1982). Structural measures such as toe keys or revetments may be necessary if bank undercutting is occurring. Brush mattresses are useful where banks can be graded to a 3H:1V or 4H:1V slope. Construction of these units creates small disturbance. Because established brush mattresses reduce local velocities, they are useful where debris and sediment need to be captured. Brush mattresses provide immediate protection against flowing water and establish a dense natural riparian zone in one or two seasons. The capabilities of this system increase with age.

Brush mattresses are generally used to cover six to ten feet of vertical bank face. This method requires a very large amount of live material.

Figure 7.10 Brush mattress with a fascine.



Brush Layers

Brush layers are alternating layers of soil and live branches on successive horizontal rows or contours in the streambank. The buried portion of the branches root to form a permanent reinforced installation, while the tips produce vegetative top growth (Figure 7.11).

Brush layers are useful in bank protection projects requiring fill, or as a rehabilitation measure for seriously eroded and barren banks (Gray and Leiser 1982). They produce an immediate barrier that repairs gully erosion and local scour holes. They effectively repair holes in earthen embankments. While the construction of brush layers generally does not require work in the channel, earthwork related to the installation of the layers may cause some disturbance. Brush layers, however, rapidly produces habitat cover and a stable vegetated bank.

Installation of brush layers is best during low flow conditions. This method requires a relatively large amount of live branches.

7.2.4 INTEGRATED METHODS

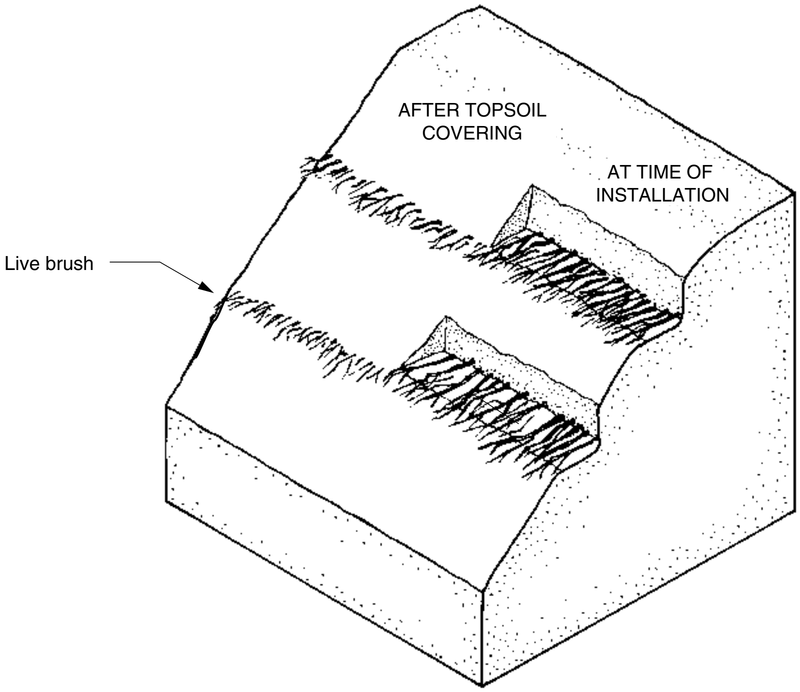
Integrated methods incorporate vegetation, soil, timber and rock. These methods include joint planting, vegetated geogrids, live cribwall, and tree revetments.

Joint Planting

This method consists of live stakes driven among rock riprap. It increases the effectiveness of the armored system by forming a root mat and reinforced filter system in the base upon which the riprap has been placed (Figure 7.12). It also helps collect sediment and debris. Because joint planting creates no channel disturbance, it is useful where rock work has to be accomplished in the summer. Once the rock is in place, live staking can be done later without further disturbance to the channel.

This method improves areas where riprap is already in place and habitat, recreational, or aes-

Figure 7.11 Brush layers.



thetic values are desired. It enables a streambank to become more natural looking and function as a vegetated riparian zone. In time, roots will add to the strength of the riprap protection.

The thickness of the existing rock layer is a major consideration in applying this technique. To achieve successful rooting, live stakes must be driven through the rock voids and into the underlying soil layer. Joint planting is more labor intensive than ordinary live staking; it also requires a moderate to large volume of live material. A plant loss of 30 to 50 percent is common with this method especially in revetments with very thick layer of riprap (Schiechtl 1980; Christensen and Jacobovitch 1992). Irrigation during the first growing season can enhance plant survival.

Vegetated Geogrid

Vegetated geogrids are similar to brush layers except that natural or synthetic geotextile materials are wrapped around each soil lift between the layers of live branches (Figure 7.13).

Vegetated geogrids are useful where slopes cannot be cut back or in bank locations requiring addition protection against strong erosive flows. The level of protection afforded by geogrids is greater than solely vegetative methods but may be less than rock methods. Vegetated geogrids are useful where fill is needed to repair local or general scour. They may be used to abate bank failure caused by toe erosion when combined with structural toe protection. If constructed with adequate soil compaction, geogrids can be constructed with a steep face and thus are valuable for repairs at sites where the banks can not be sloped back.

Vegetated geogrids immediately reinforce the bank. While the benefits are similar to those of brush layers, vegetated geogrids can be placed at a steeper angles. Vegetated geogrids capture sediment that rapidly rebuilds and stabilizes the bank. They produce rapid growth for habitat and becomes very natural in appearance and function.

Figure 7.12 Joint planting.

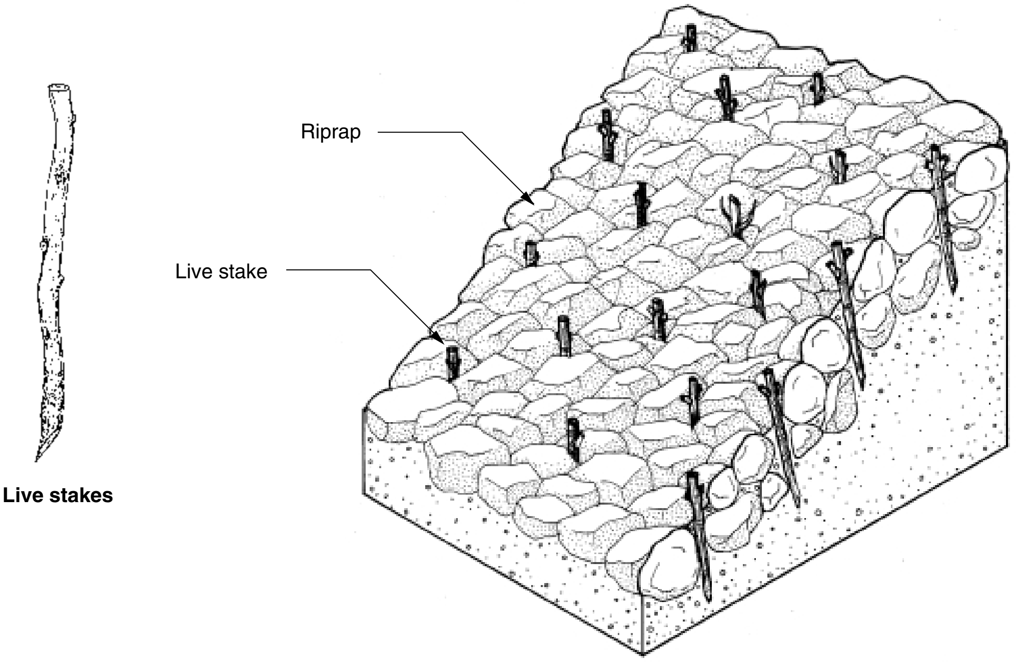
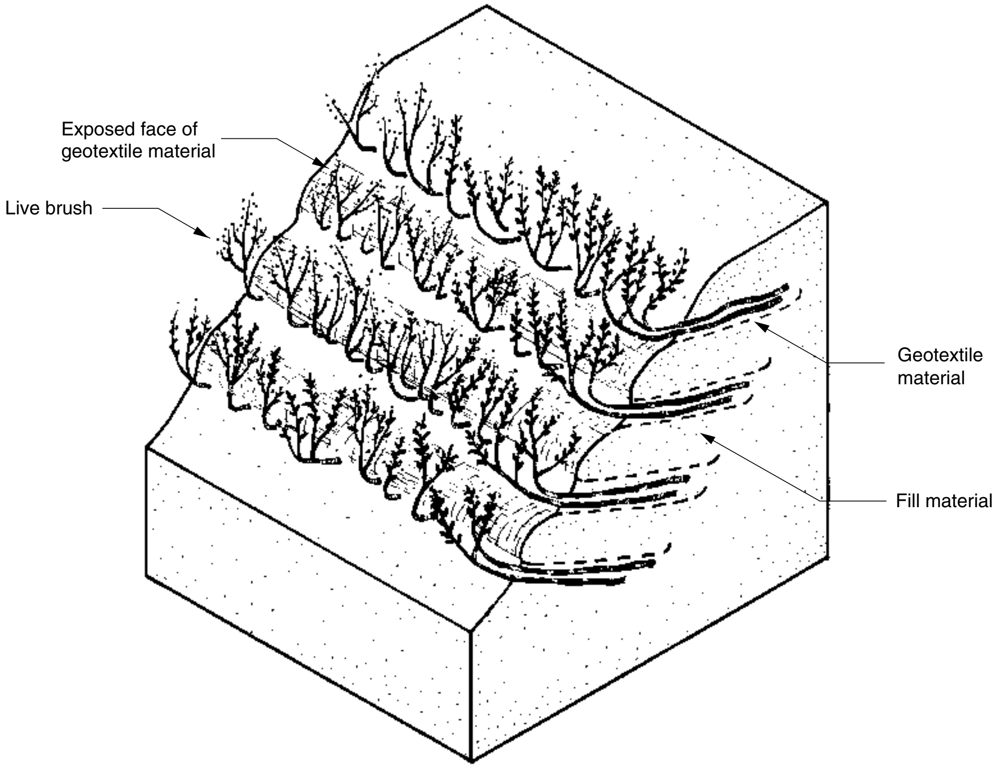


Figure 7.13 Vegetated geogrid.



Excellent overhanging material is provided immediately for aquatic habitat, and cover increases over time.

Unless rooted stock is used, geogrids are best installed while plants are dormant. At sites such as upper bank areas, irrigation during the first growing season may enhance growth and survival. Plants may be installed during the growing season if the plants are watered during the planting process.

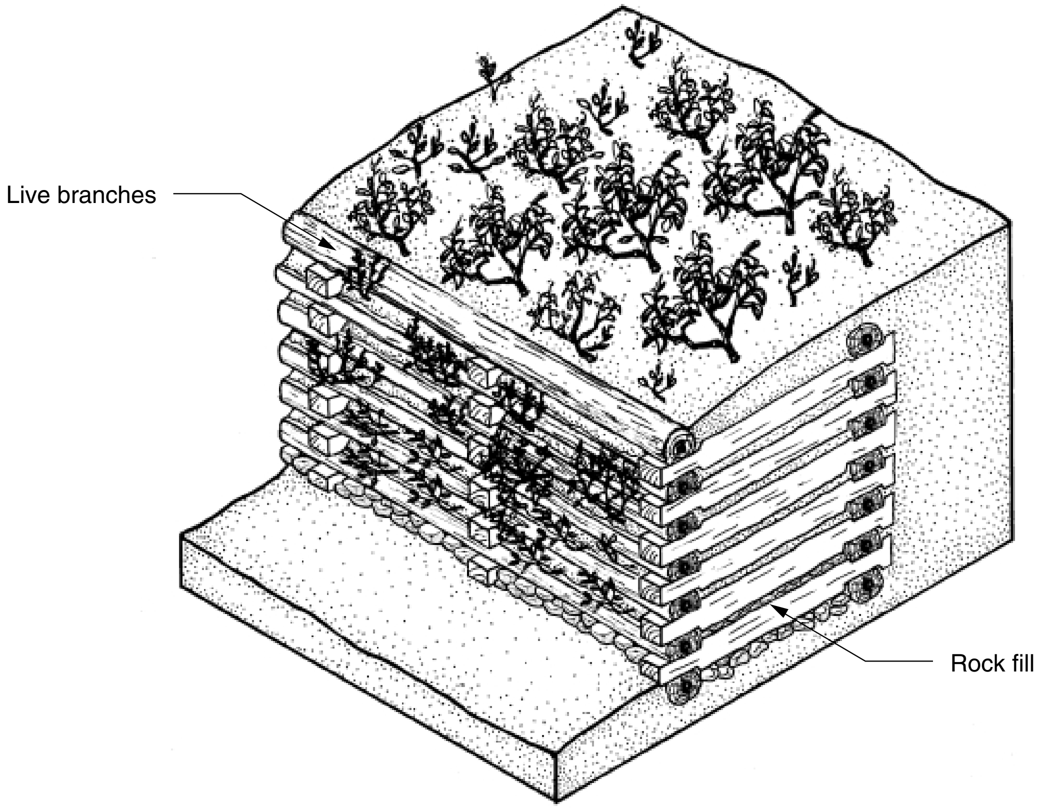
Live Cribwall

A live cribwall is a rectangular framework of logs or untreated timbers, rock, and woody cuttings (Figure 7.14). Live cribwalls are useful when space is limited and slopes cannot be cut back. They may be installed with finished streamside slopes as steep as 1H:10V. They are effective in repairing eroding banks in outside meanders or other areas where the currents are strong and fast flowing. It is useful for large areas of scour and to abate toe erosion when rock is placed in front of the structure. Because this method requires fill material, it is useful for restoring lost banks. If the area to be stabilized requires a larger-sized and more complex cribwall, the advice of an engineer knowledgeable in these designs should be consulted.

Cribwalls can provide excellent overhang cover material for aquatic habitat. The log or timber framework provides immediate bank protection, while the plants provide long-term durability.

Cribwalls need not be built to the top of the existing bank. Other methods, such as fascines or brush layers, work well on upper banks. Cribwalls should be built during low flow conditions as they often require work in the channel bed. This method requires a moderate amount of live material. Regular inspection is necessary the first year to identify and correct potential washout problems.

Figure 7.14 Live cribwall.



Tree Revetment

A pervious tree revetment, made from whole trees cabled together and held in place with rock and deadman anchors buried in the bank, is a relatively inexpensive, semi-permanent form of protection (Figure 7.15). Tree revetments are used where protection from bank scour and undercutting is needed. Additional protection can be obtained by jamming large branches or small trees behind the cabled trees. The stability of the bank above the tree revetment can be increased by using tree and shrub plantings.

Trees with a trunk diameter of 10 to 12 inches or larger are required for good barriers on large streams or rivers. Smaller trees (two to four inch trunk diameter) may be used on smaller streams. The most effective species are those with bushy tops and durable wood, such as Douglas fir or western red cedar.

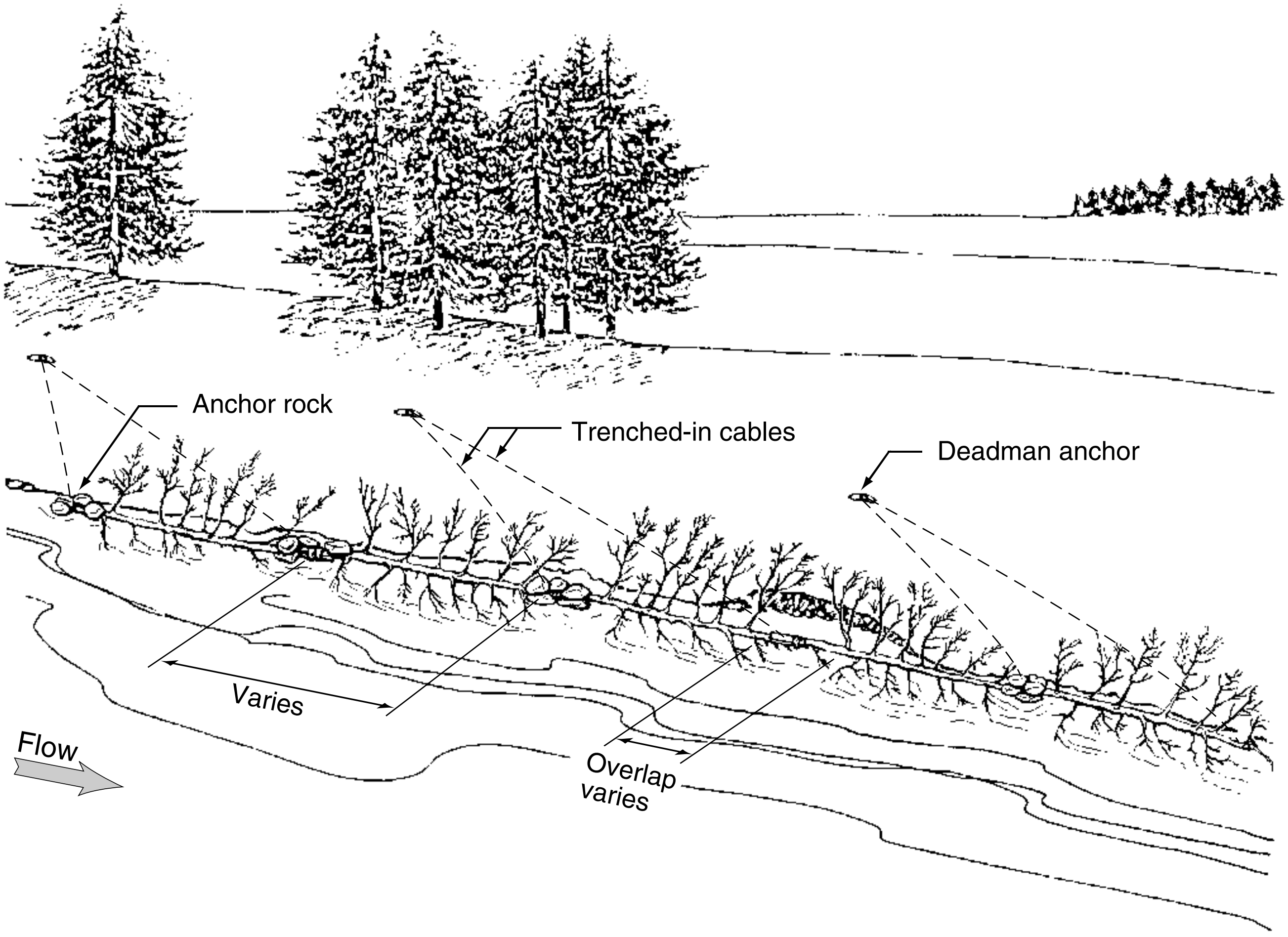
Tree revetments have a limited life and must be replaced periodically. Loss of trees through damage or deterioration will expose the bank to the current. If the revetment is not repaired, the bank will continue to undercut and erode.

Aesthetically, this method is acceptable in natural settings. As it collects sediment and begins to revegetate, it becomes more natural in appearance and function. The rate of silting which occurs in the revetment area is dependent on the type and amount of sediment being transported by the stream and the type of trees used.

7.2.5 FISH HABITAT COMPONENTS

Bank stabilization projects and other instream modifications can alter fish habitat by changing local depths and velocities, resulting in local scour or deposition at the stream bed or banks. Fish habitat may benefit from these changes if they result in spawning gravel recruitment and create resting areas in feeding zones. Bank stabilization projects may also improve overwintering condi-

Figure 7.15 Tree revetment. (Adapted from Henderson and Shields 1984.)



tions by increasing the available interstitial space and reducing water velocities. They can also provide cover either as water depth, overhangs, or visually isolated areas. The benefit of these effects on fish habitat will depend on whether or not the fish populations are limited by other factors in the stream basin.

The bank stabilization methods discussed earlier in this chapter can be improved by adding features designed specifically to benefit fish. This section describes two such features: large woody debris (e.g., trees or rootwads) placed into the bank; and boulders or boulder clusters (sometimes called fishrocks) placed in the channel.

To successfully match the requirements of various fish species and life stages to a project design, an expert in these topics should be consulted to assist with incorporating habitat components into bank stabilization projects. The type and location of habitat components added to a river should be based on the stream gradient, channel geometry, basin hydrology, intended function(s) of the structure, and available materials and site accessibility (Heiner 1989). Stream gradient, channel geometry, structural dimensions and spacing, and discharge determine the forces exerted on the habitat component. The project's habitat functions combined with the available materials and site access determine which habitat component that are feasible. These and other variables are discussed further below.

Discussion of and design criteria for full spanning structures, such as log and rock weirs that are commonly used for instream habitat modifications, is beyond the scope of these guidelines. While appropriate and needed in some situations, these structures are generally not constructed solely to achieve bank protection.

Large Woody Debris

Large woody debris is any large piece of woody material (generally defined as 0.5 feet in diameter and at least 10 feet long) that intrudes or is imbedded in the stream channel. Woody materials affect local flow velocities, streambed and streambank stability, and local stream morphology. Very large tree trunks or roots lodged against readily erodible streambanks, for example, can significantly increase localized streambank scour. The accumulation and burial of large amounts of woody debris in the streambed can dramatically increase the stability of the reach against the mobilization of streambed sediments during higher flows. Woody materials lodged at various angles to the flow can efficiently redirect the current to enhance streambank stability. The presence of woody elements benefits fish habitat by greatly increases the complexity of the currents, the entrainment and distribution of sediments, and local stream morphology.

When incorporating woody elements into bank stabilization projects, it is necessary to identify the desired engineering performance and the desired habitat benefits. Each project must be specifically tailored to meet the engineering objectives identified for the reach and the habitat requirements of the target species.

When selecting a design, it is very important to consider the factors that influence the relative permanence of wood in river systems. These include the type of wood, its size and shape, its exposure to the forces exerted by moving water, and its resistance to movement because of wedging or embedding with adjacent materials. Woody materials can be obtained as cut logs, cut stumps and rootwads, or tree trunks with roots attached. Each has particular advantages and disadvantages. Disadvantages are largely associated with the level of difficulty encountered when attempting to anchor each element in place.

The longevity of any wood will be greatly enhanced if it remains fully saturated (i.e., "waterlogged"). The maximum decay rate occurs with alternate wetting and drying, or consistently damp condition, rather than full saturation. Wood varies by species in its durability and decay resistant properties. Cottonwood and alder, even in the large sizes needed for installations along major rivers, are the most rapidly decaying local tree species. While maple will also decay fairly quickly, it is more durable than the other deciduous tree species. It is unlikely that deciduous woods can be relied on to survive for more than 5 or 10 years at best; water saturated maple may effectively double these estimates.

For maximum longevity, it is best to use more resistant coniferous species whenever possible. Of the conifers, hemlock is poorly suited because of its rapid decay rates. While very durable, Sitka spruce is often very difficult to locate and comparatively expensive because of its desirable lumber qualities and locally increasing scarcity. Douglas fir has excellent durability, especially when maintained in a saturated condition; it is also the most abundant of the commercially managed softwoods. Western red cedar, however, is the most desirable of all native local species because of its natural rot-resistant properties. Douglas fir will generally survive for at least 25 to 50 years, with cedar lasting twice this length of time. Such longevity puts these species within the normal estimates of the functional design lifetime expected for conventional riverbank stabilization installations.

Individual logs or aggregates of woody material can increase local and/or reach-specific rates of erosion by deflecting or re-directing flows. Single logs, for example, are frequently placed so that they extend into the river at a downstream angle. When placed in relatively shallow flows, the result most often obtained is increased turbulence with higher velocities both flowing around the log and redirected into the bank just immediately downstream of the log.

Conversely, placing logs at an upstream angle will deflect flows at right angles to the log away from the bank and toward the center of the stream (Figure 7.16). Deeper, higher-velocity flows will incrementally scour a pool around and under the end of the log. This effect, when distributed over a series of logs placed along an outer meander bend, can effectively shift the deeper, faster flows away from the toe of the riverbank slope. Relocation of the thalweg of the river, even by a modest distance, can markedly enhance the longevity and performance of riverbank stabilization measures.

Boulders/Boulder Clusters (Fishrocks)

Fishrocks are large, irregular boulders used to create fish habitat by producing a diversity of velocities and depths. Additional cover and rearing areas are provided by the deep water, air bubbles, and turbulence around the rocks. In addition, individual boulders or groups of boulders may aid bank stabilization efforts by deflecting flows away from unstable banks.

Fishrocks can be used to achieve many different objectives, depending on where they are placed and how they are arranged (Figure 7.17). Although boulder placements are the simplest fish habitat structures, the hydraulics surrounding them are complex. Careful planning and the use of hydraulic criteria to choose and place boulders will enhance their success.

The first step in predicting the results of rock placements is to analyze the existing flow patterns and streamlines in plan and profile view and then visualize how the rock will change them. This can then aid in estimating the pattern and extent of scour and deposition.

Clusters of boulders have several advantages over single boulders. Boulder clusters provide greater stability, have a greater diversity of depth and velocities, and trap woody debris more efficiently than single boulders. Additional cover for fish is provided in the spaces between the boulders.

Irregularly-shaped, angular boulders of durable rock should be used. Abrupt boulder edges

Figure 7.16 Bank protection using large woody debris.

ALIGNMENT OF LARGE WOOD IN THIS CONFIGURATION NO LONGER USED DUE TO SAFETY CONCERNS FOR RECREATIONAL RIVER USERS. (APRIL 2009).

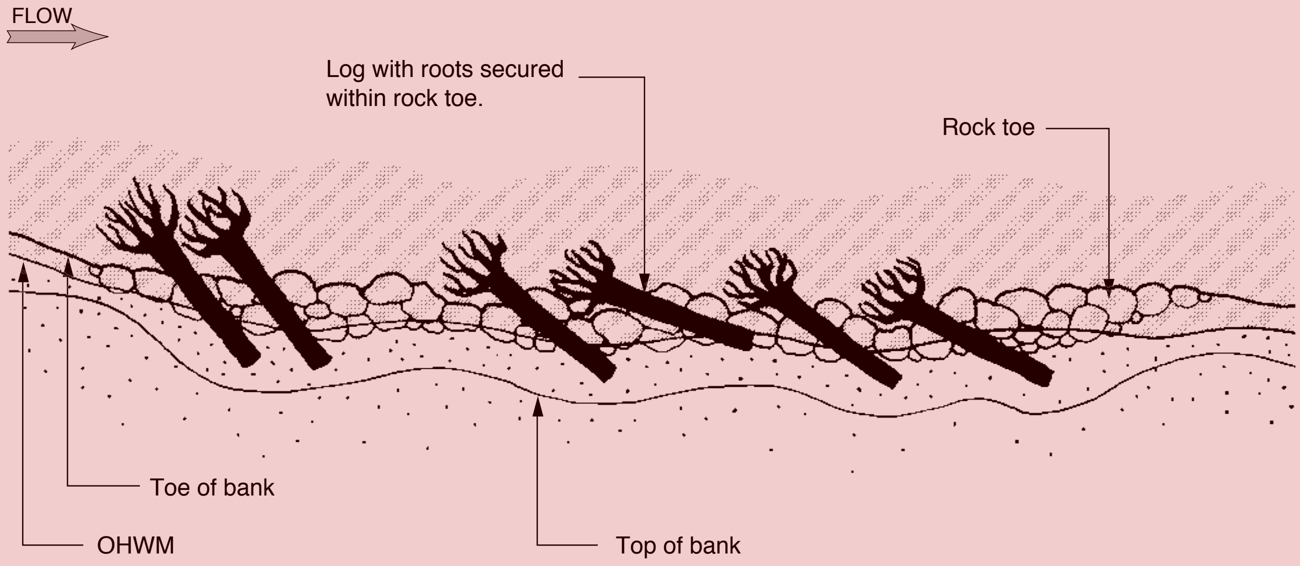


Figure 7.17 Boulder clusters. (Adapted from Orsborn et al. 1985.)

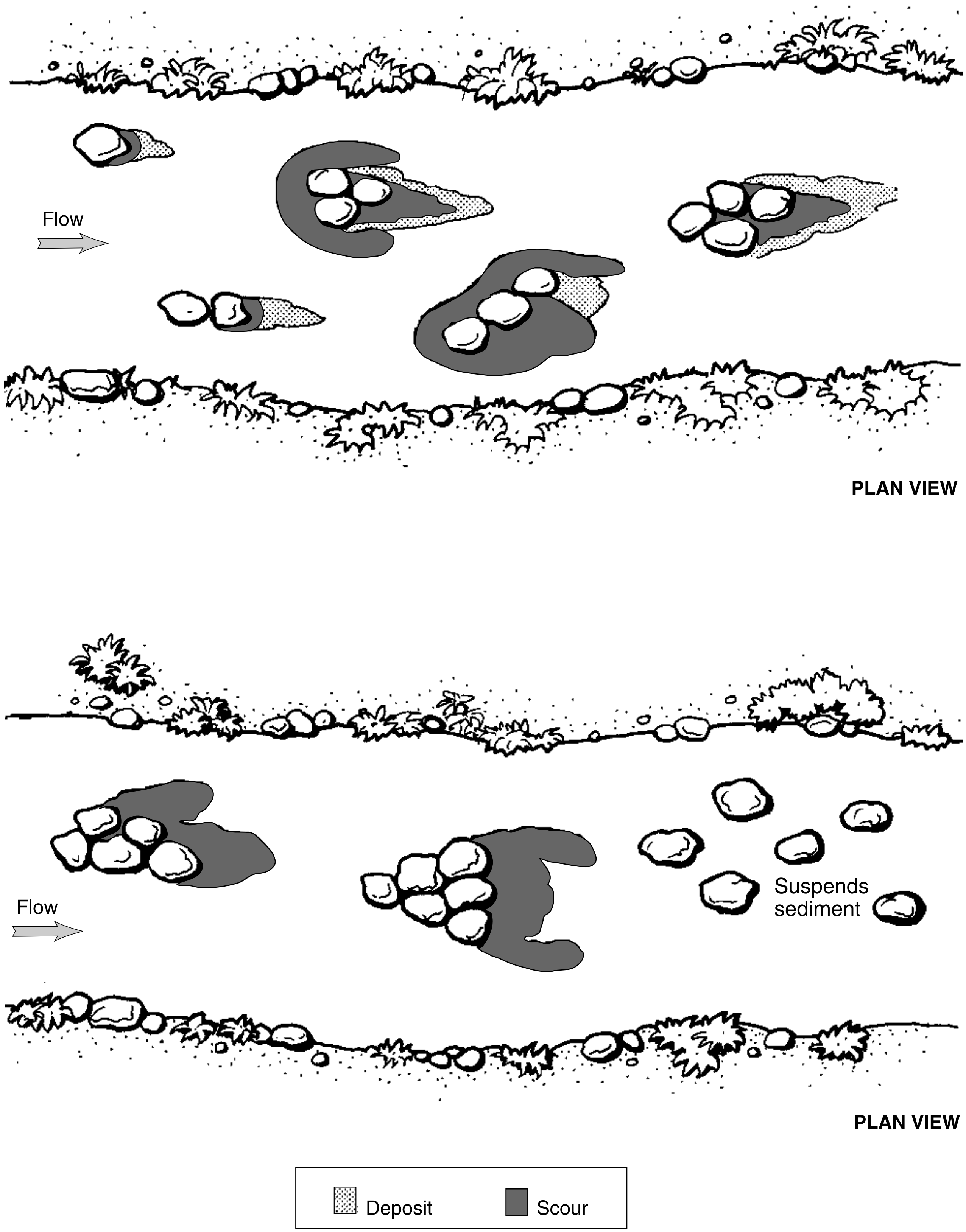


Table 7.3 Recommended rock sizes for fishrocks. (Federal Highway Administration 1979.)

Channel Width (ft.) (summer flow)	Water Depth (ft.)	Length of Rock (ft.)
≤ 20	1.0 to 2.5	2.0 to 4.0
20 to 40	1.0 to 3.0	3.0 to 8.0
40 to 60	1.5 to 4.0	4.0 to 12.0

create turbulent eddies and enhance the scouring potential of the rock (Cullen 1989). Angular rock is also less likely to roll in the current (Moreau 1984). The irregularities will provide additional hiding cover for fish (Crispen 1988).

The boulders should not be so large that they cause bank erosion or overtopping. Maximum scour occurs when the water level is at the top of the rock (Fisher and Klingeman 1984). The Oregon State Highway Division (1976) recommends that no more than one third of the channel area be blocked. The Federal Highway Administration (1979) cautions that no more than one fifth of the summer low flow area be blocked unless the stream gradient is greater than three percent. These recommendations may be conservative and oversimplified in that the stability of the rock and the channel depends on many more factors than simply flow blockage.

The rocks should be large enough not to be washed away during high flows. The size of rock required depends on stream size, flow characteristics, substrate stability, and rock shape. Crispen (1988) suggests that fishrocks should be at least as large as rocks naturally maintained in the stream.

The Federal Highway Administration (1979) recommends using 2-foot diameter, 1000-pound rocks in velocities of up to 10 feet per second and 4-foot diameter rocks in velocities of 10 to 13 feet per second. In addition, they provide size guidelines based on channel width and depth (Table 7.3). Other suggestions from various sources suggest that boulders should be at least 2.0 to 6.5 feet long or have a volume of greater than 0.65 cubic yards (British Columbia Ministry of the Environment 1980; Ward and Slaney 1981; Moreau 1984; House and Boehne 1985; Wesche 1985).

Highway agencies, concerned with protection of the roadway, advise that if potential flooding or bank erosion is of concern, high flows should overtop boulders to clear trapped debris (Oregon State Highway Division 1976; Federal Highway Administration 1979). If the risk of damage to property and improvements is low, debris should be left around fishrocks for additional cover.

Boulders with blunt faces create large upstream scour holes and then tend to tip into this hole (Fisher and Klingeman 1984; Cullen 1989). Rocks should be selected and positioned so that this does not occur. Increased stability can be achieved by placing boulders in clusters. Seehorn (1985) recommends the use of boulder clusters over isolated boulders. While the scour pattern around boulder clusters depends on the cluster pattern, it often resembles a horseshoe.

When placed in riffle and glide areas, boulders can create pocket-like pools that provide resting areas for rearing or migrating fish (Rosgen and Fittante 1986). Avoid placing rocks at sites with fine or unstable beds that scour readily (British Columbia Ministry of Environment 1980; Ward and Slaney 1981). As with blunt-faced boulders, rocks placed in these sites tend to sink into their own scour holes unless the substrate is armored (Fisher and Klingeman 1984; Cullen 1989). Similarly, avoid placing rocks in depositional areas where the rocks may become buried by sediment (Ward and Slaney 1981). Occasionally, rocks may be used in such areas to encourage deposition.

7.2.6 SUMMARY OF DESIGN CONSIDERATIONS

To help designers select solutions appropriate for each situation, Table 7.4 summarizes each method including relative quantities of material, major limitations, and costs. Installation procedures are discussed in Chapter 8. This table should be used in conjunction with the numerous design factors discussed in the previous chapters.

7.3 DESIGN DRAWINGS, PLANS AND SPECIFICATIONS

Conceptual designs explore ideas and relationships among functions, activities, and spaces. They serve as a basis for further development, as a means of conveying graphic concepts to other individuals working on a project, and a medium for feedback during the design development stage. They are rough sketches lacking detail, serving mainly to get preliminary ideas on paper. There are no right or wrong conventional symbols.

During design development, the rough sketches and ideas developed in the conceptual design phase are tested and refined. The designer evaluates possibilities identified in the conceptual phase and rejects, adds to, or modifies them. This phase results in drawings that include specific information on spatial organization, material, and sizes of features. Called "presentation drawings", these are used to communicate ideas and obtain feedback for later design refinement. Presentation drawings should be fairly realistic and self-explanatory, with limited text for labels. The level of detail provided is intermediate between conceptual and final plans. The plan view (straight down from above) is the most commonly used projection in the design development stage. Section-elevations or cross-sections are also useful to show the vertical arrangement of the streambank.

Final designs are prepared for the people who actually install the project. These should clearly describe the exact sizes, shapes, quantities, types, and locations of all project elements. This information is used to prepare bids, as well as in the actual construction process. The drawings should contain a site plan, grading plan, layout, irrigation, planting, and detail sheets. The graphics must be complete, accurate, and very easy to read. They should be accompanied by detailed written instructions, called construction specifications, which supplement and clarify the graphic on the drawings. An example of construction specifications is provided in Appendix D.

In addition to the elements described above (specific quantities, densities, species), final design plans should include: a key to symbols for deciduous and coniferous trees and shrubs, paving, riprap, grass, and forbs; scale (graphic or numerical value: graphic scales have the advantage of changing at the same rate as the rest of the page if enlarged or reduced); and a North arrow (Figure 7.18). A complete list of information that should be included in the final project drawings and construction documents is provided below:

- Overall location plan showing access to site from local highways (drawn at any appropriate scale).
- A drawing of the entire bank or repair area, locating each type of treatment.
- Right-of-way and easement areas.
- An elevation drawing of the repair, identifying whether the elevation is truly vertical or parallel to the slope. Include topographic information (one foot intervals) of the existing and proposed contours.
- Existing river protection facilities and channel hardpoints such as large rocks or bedrock areas.
- Roads, gutters, swales, and other physical features.
- Existing property improvements (e.g., homes and other buildings) and utilities including septic drainfields.
- Temporary construction staging area for material stockpiling and equipment storage.
- Top and toe of bank and water levels (ordinary high water and design flows).
- Proposed areas of cut and fill.

Table 7.4 Summary of design considerations for various bank stabilization methods.

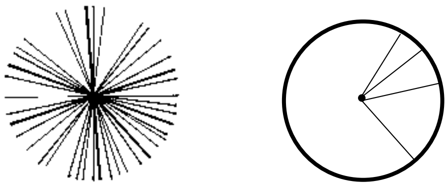
Method	Recommended season to install[1]	Position on bank	Quantity of live material required	Major limitations or drawbacks	Recommended use	Cost
brush layers	when plants are dormant	above ordinary high water	very large[2]	construction during low flow	sites requiring fill; scour holes	moderate[3]
brush mattress	when plants are dormant	above ordinary high water	very large[2]; 10 to 20 lbs vegetation per sq. yd.[3]	not useful on steep banks, construction during low flow	high velocity or high gradient, where slopes can be cut back	2-5 hr/sq. yd. to install
fencing	any season	in overbank areas	none	does not stabilize bank	in conjunction with other methods	varies with type; $5-15/ft.
joint planting	when plants are dormant	above ordinary high water	moderate to large	thick riprap may be difficult to stake	where riprap is required or already in place	5-7 sq. yd. per hour, including cutting and transport[3]
live cribwall	when plants are dormant	from below channel bed; vegetation above ordinary high water	moderate[2]	may require work in channel bed; constructed usually during low flow	limited space, strong current, steep banks	varies
fascines (wattles)	when plants are dormant	above ordinary high water	moderate[2]		where dissipation and direction of water movement downslope is needed	low cost[3]; $0.91 to $2.44 per ft[4]
live stakes, cuttings	when plants are dormant	above ordinary high water	moderate to large for stakes, small for cuttings	labor intensive; vulnerable to vandalism	areas with minor scour, fertile soils; sites with limited equipment access	cuttings: $0.35-0.71/sq. yd. [4]
herbaceous ground cover	spring or early summer; late summer to early fall	above ordinary high water	small (hydroseed)	see tables 7.1 and 7.2	where large or woody vegetation is not desirable; where fast cover is needed	varies; $0.01-0.15/sq. yd.[4]
rock riprap	any season (may be limited by permit provisions)	below ordinary high water; or higher on bank as required	none	generally not useful on steep slopes (greater than 2H:1V)	where toe armor is needed; high velocity areas; flood-fighting emergencies	varies; $25-30/cu. yd. placed

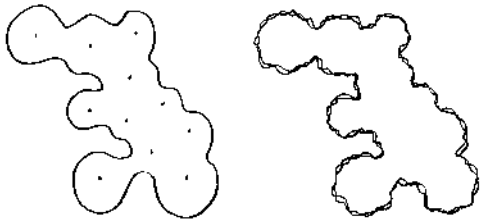
Table 7.4 Summary of design considerations for various bank stabilization methods, continued.

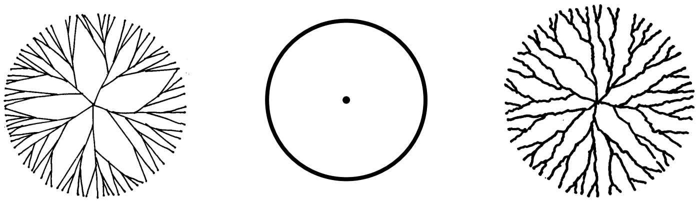
Method	Recommended season to install[1]	Position on bank	Quantity of live material required	Major limitations or drawbacks	Recommended use	Cost
rooted stock	fall to spring	above ordinary high water	varies	summer installations may require irrigation	when large plants for cover is desired	varies with size and species
tree revetment	any season	at ordinary high water	varies	must be replaced periodically	for protection from bank scour and undercutting	varies
vegetated geogrid	when plants are dormant	vegetation above ordinary high water	very large	requires work in channel bed, construction during low flow	limited space, steep slopes that can't be cut back, high velocity	slightly more than gabions; least expensive retaining wall[3]

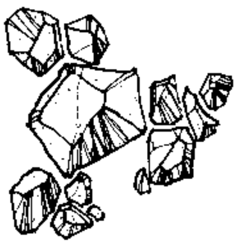
1. *Most vegetative methods have higher survival if constructed while plants are dormant and when the material is freshly cut; many will survive at other times, however, if adequate moisture is available or provided and the material is not damaged by construction activities.*
2. *Dickerson 1992.*
3. *Schiechtl 1980.*
4. *Weaver and Madej 1981.*

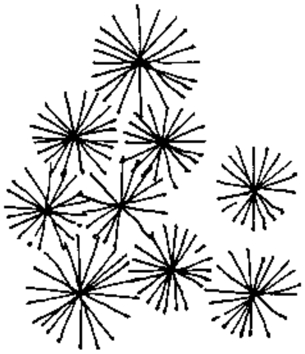
Figure 7.18 Examples of symbols for plans and specifications.

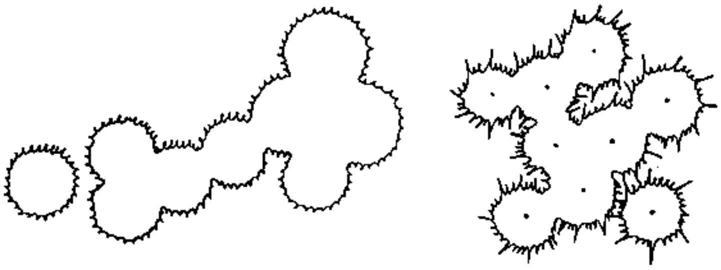

Evergreen trees

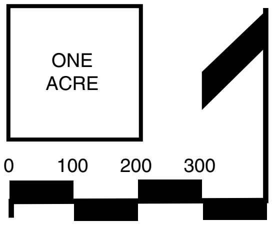

Plant groups


Deciduous trees

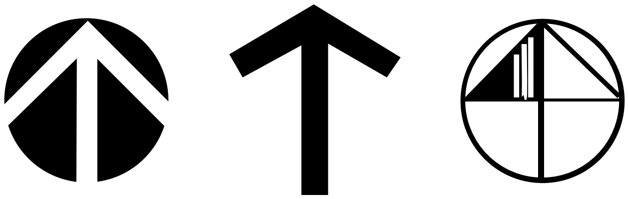

Rocks


Evergreen shrubs


Shrubs



Scale and north arrow


North arrows

- Existing trees and major plant materials with clear indication of whether each item is to remain or be removed.
- Configuration of the design solution around existing (remaining) trees and other vegetation.
- The zone around existing trees to be protected during construction.
- Areas of bank failures and extent of proposed design.
- Sources of plant materials.
- Plant names and sizes.
- Location of temporary irrigation systems if applicable.
- Power and water source and point of connection if applicable.
- Name and phone number of contact person representing the project sponsor.
- Any special conditions unique to the site.

RECOMMENDED REFERENCES FOR ADDITIONAL INFORMATION

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