APPENDIX B

Stream Corridor Restoration Profile Sheets

Chapter 4 Profile Sheets from the Urban Stream Repair Practices Manual (CWP, 2005)

R-3	Boulder Revetments
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Chapter 4: Stream Repair Practices Profile Sheets

This chapter provides profile sheets for 33 different stream repair practices. Each profile sheet generally describes the repair practice, along with design schematics and photos of what it looks like in the field. Each sheet then describes the nature of any stream habitat feature created by the practice. The feasibility of the practice is assessed in terms of the stream types where it works best and the channel processes where it should be avoided. The bulk of each sheet is devoted to practical guidance on design, construction and maintenance, with specific reference to unique urban stream considerations reviewed in preceding chapters.

Each profile sheet also reports unit cost information, where available, for developing initial planning-level cost estimates for concept designs. The unit cost data for each practice was derived as the average of up to four independent sources (MD (2), NC, and WA). Each profile sheet concludes with a handful of design and construction specifications drawn from state, regional, national or international sources. These design resources, which can be accessed over the internet, were selected to provide geographic balance across the country.

The reader may also want to consult the matrices presented in Section 3.5 to see how individual stream repair practices compare with respect to design objective, stream suitability, site feasibility and habitat features created.

A directory of the stream repair profile sheets is provided below.

Profile Sheet **Page**

Stream Cleanup Practices

Simple Stream Repair Practices

Comprehensive Stream Repair Applications

R-3

Stream Repair: Hard Bank Stabilization

BOULDER REVETMENT

Description

A boulder revetment is a stream repair practice used to stabilize eroding streambanks. The revetment consists of a series of boulders placed in varying configurations along an eroding streambank to prevent erosion at the toe and in some cases, the middle and upper streambank zone (Figure 1).

Habitat Features Created – Boulder revetments have only a limited potential to enhance stream habitat. As most boulder revetments are made of irregularly shaped boulders, there is limited potential to create void space below the water surface. Boulder revetments have a more indirect role in habitat enhancement by reducing streambank erosion and subsequent sediment influx to the stream.

Feasibility

The toe of the streambank is the most erosion prone area of an urban stream, with the lowest third of the bank experiencing the greatest erosive forces. Erosion at the toe of the streambank often results in failure of the entire bank, which greatly increases sediment delivery to the stream. Boulder revetments help protect vulnerable streambanks in situations where softer bioengineering practices are not practical because of high flow velocities and shear stress.

Boulder revetments are an effective bank stabilization method when the cause of bank failure is toe erosion, bank scouring, or urban stream enlargement. Boulder revetments are not recommended for streambanks that are failing due to active downcutting (i.e., stream degradation). In these situations, revetments can be undermined as the streambed drops, unless the underlying grade control problem is addressed.

Boulder revetments often serve as the foundation for bank shaping and other bioengineering measures on the middle and upper banks (Figure 2). Boulder revetments can provide complete bank protection on smaller streams with bank heights of less than two feet.

Boulder revetments are a hard and non-deformable practice that prevents the normal processes of lateral channel adjustment and meander migration from occurring.

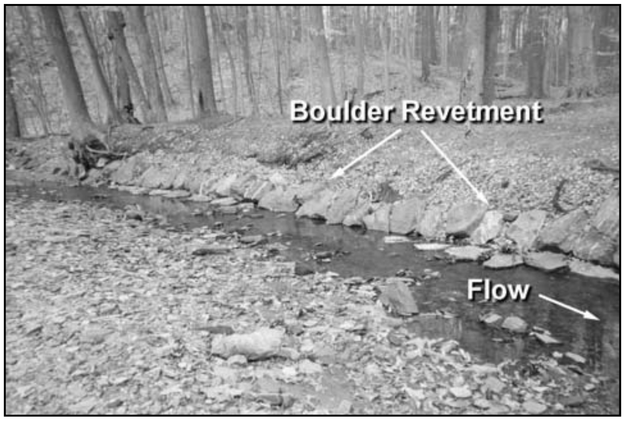


Figure 1: Boulder revetment along a meander in an urban park

Figure 2: Boulder revetment with willow plantings along an urban stream

As such, their use should be confined to the outer edges of the meander corridor to protect valley side slopes and terraces from further erosion. Deformable bioengineering practices are generally preferred within the meander corridor, where feasible (Figure 3). Over-reliance on boulder revetments in an urban stream may simply transfer future channel adjustments to upstream and downstream areas that are presently stable.

If the bank substrate is composed of sandy, silty or organic materials, scour may cause the revetment to settle or fail. Designers should ensure that the stream substrate can support the weight of the revetment and that the revetment extends below the potential depth of scour (Figure 4). Boulder revetments require good access for heavy equipment, and a staging area to stockpile boulders and equipment. Additional construction costs are incurred when the staging area is distant from the bank repair site, and smaller, lighter equipment is needed to access the site.

Implementation

Most boulder revetments consist of a course of footer boulders and one or two courses of revetment boulders. Figure 5 depicts double boulder and large boulder revetment configurations. Unlike imbricated rip-rap revetments, boulder revetments are not intended to be self-supporting walls, and may use smaller, less blocky boulders. The size of the boulders should be set so they will not move during flow velocities expected for the 50 or 100-year flood level. Boulder revetments are suitable on straight reaches or meander curves, as long as the potential depth of scour is accounted for. Use of native rock is recommended where practical. Bright white or off-colored stone may not be aesthetically pleasing in regions where native stone is dark.

Another design variation is the deformable toe revetment. This new streambank treatment is designed to be stable for the time it takes to establish streambank vegetation, after which the boulders are allowed to move. Deformable toe revetment designs use boulder sizes that will be stable for more frequent design floods (5- to 10-year return frequency) and wrap them in biodegradable erosion control fabrics. The fabric ensures that the boulders will be stable for the life of the fabrics (about 2 to 5 years), which gives enough time for vegetation to take hold. At that time, the streambank is allowed to laterally adjust and the meander can migrate.

At times, a single row of three to four foot diameter boulders may be used to create a revetment. When large boulders are used, it is important that they be entrenched deeply enough to prevent channel scour from dislodging them. Otherwise, the construction of a large boulder revetment is very similar to single and double boulder revetments, minus the footer stones.

Construction – A single boulder revetment is created by first excavating a trench below the invert of the stream and extending it along the toe of the eroding streambank. Filter cloth is

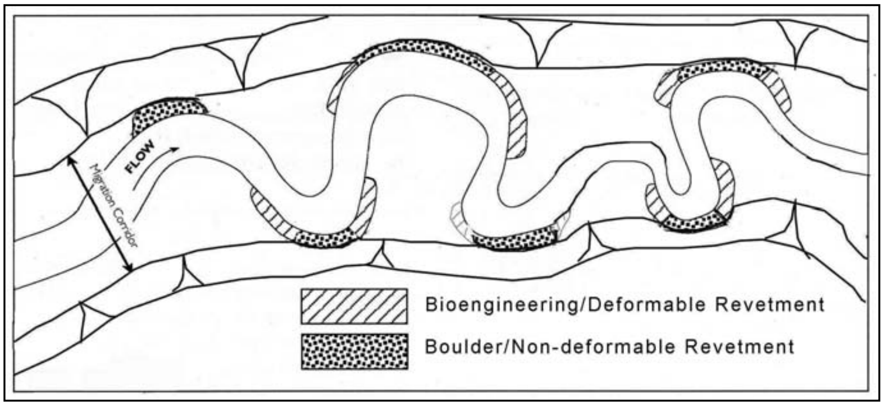


Figure 3: Appropriate use of deformable (soft) and non-deformable (hard) bank protection practices
Source: Miller and Skidmore, 2000

Figure 4: Boulder revetment failure due to toe scour

then placed in the trench and extended up the streambank. A series of large flat/rectangular boulders are then placed in the trench as footers. The bottom of the footer boulders must be below the expected depth of scour. Once the footer boulders have been installed, revetment boulders are placed on top. If protection is needed higher on the bank, a second course of stones may be placed on top of the first, forming a double boulder revetment. The face of the revetment should be made as rough as possible to decrease current velocities on the streambank. The revetment should generally extend at least one-third of the streambank height to protect the most erosion prone area. Once the revetment is installed, the upper streambank should be graded and shaped to transition into the top of the revetment. Streambed vegetation and erosion control mats are then installed on exposed soils.

Other streambank stabilization practices are often placed above the boulder revetment. Soil lifts and bioengineering practices are often combined with toe revetments to protect the upper streambank. In these cases, the boulder revetment should extend to a height above which vigorous perennial vegetation can survive.

Maintenance/Monitoring – Initially, inspections of the boulder revetment should be undertaken after the first few large storms to ensure that the boulders are stable and upper bank plantings are surviving. Once this has been confirmed, annual inspections are warranted. No special maintenance is needed for boulder revetments, except for occasional replacement of dead/dying vegetation.

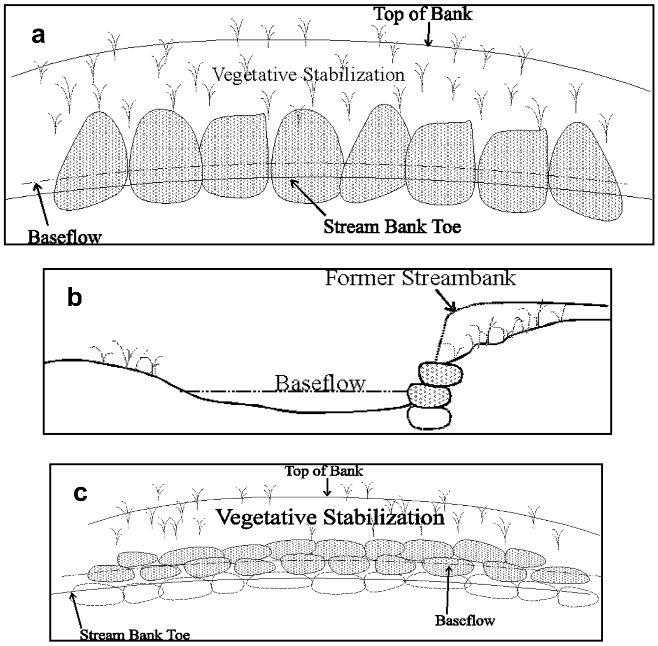


Figure 5: (a) Large boulder revetment, (b) Profile of boulder revetment, (c) Plan view of boulder revetment

Cost – The unit cost to install a single boulder revetment ranges from $20 to $40 per linear foot of eroding streambank. Cost for boulder revetments increases when double layer treatments are used and additional treatments are needed on the upper bank.

Further Resources

Washington State Integrated Streambank Protection Guidelines (2002)
http://www.wdfw.wa.gov/
(roughened rock toes)

Maryland Guidelines to Waterway Construction (2000)
http://www.mde.state.md.us/assets/document/wetlandswaterways/sec2-11.pdf

NRCS Engineering Field Handbook - Chapter 16 Streambank and Shoreline Protection
http://www.nrcs.usda.gov/technical/ENG/efh.html

Ohio Stream Management Guide
http://www.ohiodnr.com/water/pubs/fs_st/streamsfs.htm

R-5

Stream Repair: Hard Bank Stabilization

IMBRICATED RIP-RAP

Description

Imbricated rip-rap is a stream repair practice that provides hard bank stabilization and consists of large boulders arranged as interlocking blocks along the streambank toe. Imbricated rip-rap is a structural solution to stabilize high streambanks from erosion where it is not possible to shape the streambank to a stable angle or apply other deformable measures (Figure 1).

Habitat Features Created – Although imbricated rip-rap is a hard streambank stabilization practice, it can provide habitat enhancement in the form of gaps beneath the water surface between the revetment stones, which provide overhead cover and refuge areas for fish.

Feasibility

Imbricated rip-rap is often used along entrenched streams with severe instability that cannot be mitigated by other techniques because of space and infrastructure constraints. Imbricated rip-rap should only be used where continued bank failure would result in the loss of property or infrastructure, or massive sediment movement into the stream (e.g., slope failure), and where no other bank stabilization practices are feasible. Also, if the bed substrate is composed of sandy, organic or silty materials, it may not support the weight of the revetment. In these cases, additional foundation materials may be required.

Figure 1: Imbricated rip-rap revetment protecting utility infrastructure

Imbricated rip-rap is a non-deformable practice that eliminates the ability of the stream to adjust laterally in response to changing flow and sediment transport conditions. Extensive use of imbricated rip-rap may simply shift where these natural adjustments occur upstream or downstream of the practice. Imbricated rip-rap makes sense when streambank instability is the result of stream channel processes, such as toe erosion, channel scour, meander migration and lateral adjustment. If streambank failure is caused by slope instability or mass wasting unrelated to stream channel processes, these upland problems must be corrected prior to installation.

In addition, imbricated rip-rap is <u>not</u> recommended for urban stream channels that are experiencing or expected to undergo vertical degradation or incision. In any case, footer stones must be installed below the depth of the expected scour. Imbricated rip-rap should be used in tandem with grade control practices, if there is potential for vertical channel degradation.

Implementation

Rock size determines the maximum height of the revetment. In general, the height of the revetment should not exceed three times the long axis of the average rock or 10 feet, whichever is less. Filter fabric and/or a graded gravel filter should be installed between the revetment and the existing streambank surface to prevent soil piping.

Imbricated rip-rap can be close to vertical but should be sloped back slightly for stability (i.e., 1H:6V). This practice requires large boulders that are generally flat or rectangular in shape so that they can be stacked securely and with structural integrity. The structural properties of imbricated rip-rap make it one of the few practices that can be installed along near vertical streambanks. The boulders should be sized so that they will remain stable at the expected current velocity of the design flood event, and footer boulders located below the expected depth of future scour. Methods to estimate stable rock size and the depth of the scour can be found in Copeland *et al*. (2001).

Construction – Imbricated rip-rap is installed in the same general manner as a boulder revetment but can rise to protect the full height of the streambank (Figure 2). In other cases, imbricated rip-rap is used to protect the bottom half of the bank, with the upper bank laid back and vegetatively stabilized. The first step in the construction sequence is to grade the streambank to the desired slope. After the streambank is graded to the desired angle, a trench should be cut along the toe of the bank for the footer stones. The depth of the footer trench should allow stones to extend down to below the expected depth of scour. More than one course of footer rocks may be needed for the foundation. A layer of geotextile fabric is then laid from the top of the streambank down into the footer trench, to prevent the loss of streambank soils through the revetment.

Individual footer stones are placed on top of the filter cloth in the trench. The largest stones should be placed lowest within the revetment. Once the first course of footer stones is in place, the remaining trench can be backfilled with smaller rip-rap as toe protection. A key design element of imbricated rip-rap is the spacing of the first layer of revetment blocks, which should be separated by a gap of 12 to 18 inches.

Gaps beneath the water surface serve as overhead cover and refuge for fish (Figure 3). Succeeding courses are stacked with staggered joints between each course. Free draining gravel should be backfilled between the revetment stones and the filter fabric as each course is laid. The process is continued until the desired wall height is reached. The existing top of the bank is then laid back into the imbricated rip-rap wall and stabilized with vegetation (Figure 4).

Maintenance/Monitoring – Imbricated riprap should be inspected for structural integrity monthly for the first six months, or after any large storm events during the first year, with annual inspections thereafter.

Cost – Reported unit cost for imbricated rip-rap ranges from $60 to $90 per linear foot, with higher costs for greater bank heights stabilized.

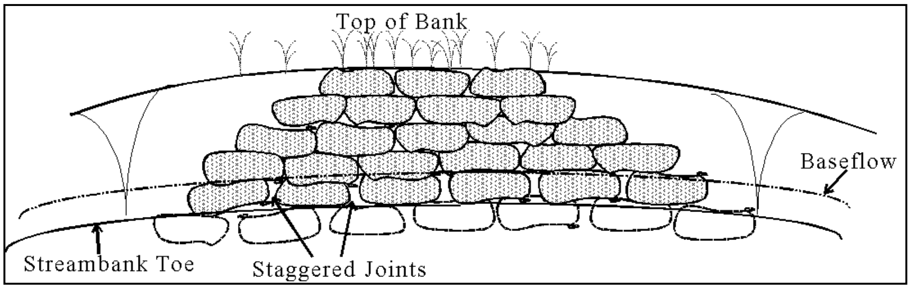


Figure 2: Longitudinal view of an imbricated rip-rap revetment

Figure 3: Spacing between the first course of revetment stones

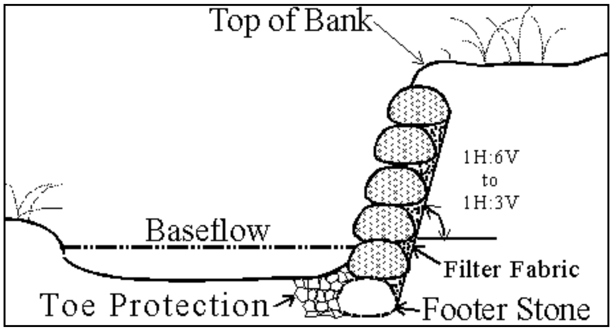


Figure 4: Cross-section view of imbricated rip-rap revetment

Further Resources

Maryland Guidelines to Waterway Construction (includes standard details for imbricated riprap)

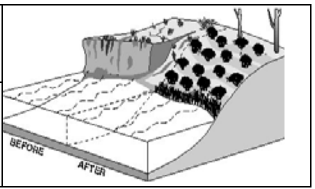
http://www.mde.state.md.us/assets/document/wetlandswaterways/sec2-2.pdf

Virginia Stream Restoration and Stabilization Best Management Practices Guide
http://www.dcra/state/va.us/sw/docs/streamguide.pdf

R-8

Stream Repair: Soft Bank Stabilization

STREAMBANK SHAPING



Description

Streambank shaping is a stream repair practice used to achieve a more stable bank slope. It consists of changing the contours of an eroding streambank without changing the streambank toe or the planform of the stream. Streambank shaping can be used as a stand-alone practice when streambank instability is the primary cause of bank failure, or it can be combined with toe protection practices when toe erosion or channel degradation are causing the bank to erode.

Habitat Features Created - Streambank shaping does not directly enhance in-stream habitat, but can reduce fine sediments delivered to the stream.

Feasibility

As a stand-alone practice, streambank shaping can be applied to urban streams that are incised but have relatively stable longitudinal slope and channel width. Incised streams are often in the process of creating a new floodplain at a lower elevation in the stream channel, and have tall, vertical, and unstable streambanks, which far exceed the root zones of riparian vegetation. In other cases, riparian vegetation has been removed by grazing or mowing, making the banks prone to failure. If the streambank toe is not actively eroding, streambank shaping in combination with riparian plantings may be sufficient to restore streambank stability (Figure 1). In these cases, designers simply remove bank material that will likely be eroded in the future and transported downstream. Careful streambank shaping helps an urban stream adjust its cross-section to the increased hydrology produced by upstream watershed development.

If toe erosion is the primary cause of bank failure, additional hard streambank treatments, such as boulder revetments, coir logs or A-jacks, need to be installed to protect the toe before bank shaping can begin (Figure 2).

The bank angles and channel dimensions of urban streams often depend on stream classification and regional stream geometry (Rosgen, 1997). The type of soil and vegetation at the streambank also dictate stable streambank angles. Also, the potential increase in channel cross-section may improve the capacity of the channel to pass floodwaters. Adequate room must be available within the stream corridor to lay the bank back to a stable angle. Constraints such as trails, utilities and other infrastructure in the corridor should be carefully evaluated.

Implementation

The feasibility of streambank shaping as a stand-alone practice requires a thorough assessment of channel cross-section and planform. The existing and future channel cross-section should be stable and show no evidence of active enlargement or degradation. Some planform or lateral adjustment is allowable, if it occurs within the meander corridor. However, if the lateral adjustment is expected to extend outside the meander corridor and erode valley side slopes or infrastructure, other bank protection measures should be substituted. It is also important to note that streambank shaping alone will not arrest active widening or degradation of the stream

Figure 1: Streambank shaping along an urban midwest stream

Figure 2: Streambank shaping in combination with boulder revetment and rock vortex weirs

Therefore, designers need to carefully analyze the stream reach to determine the rate of toe erosion and whether the streambed is actively cutting down. Useful evidence to confirm slow toe erosion rates is build up of failed upper bank sediment along the toe. Conversely, fallen upper bank sediments tend to be quickly transported downstream from actively eroding toes.

A longitudinal gradient field survey may be needed to determine if the stream is actively downcutting. The most notable indicator of downcutting is the presence of a knickpoint below the streambank shaping site. Knick points migrate upstream and are a strong indicator of active streambed degradation. Absence of sediment deposits or bars in the stream channel may also indicate excessive channel erosion and potential bed degradation. If fallen upper bank material is present along the streambank toe and there is no evidence of active bed degradation, then shaping and re-vegetating the streambanks alone may restore bank stability. This is often the case along older urban streams where the channel has adjusted to altered hydrology and the process of channel adjustment has slowed.

Additional toe protection and grade control practices may be needed if the field assessment indicates active toe erosion and/or bed degradation are occurring. Shaping of the upper streambank can begin once other stream repair practices have addressed these problems (Figure 3).

Streambank shaping is something of an art. Designers should examine urban reference streams with stable vegetated streambanks to get an idea of locally appropriate streambank angles and vegetation types. Hydraulic analysis can be helpful to determine the type of bank material that can withstand the shear stress produced by bankfull discharges. Fischenich (2001a) has developed useful equations to determine bank stability of different bank materials based on the velocity of projected flows.

The grading plan should clearly specify where and at what angle the streambank is to be graded, the limits of grading and disturbance, and specifications for re-vegetation. Streambank shaping can generate large volumes of excess soil that need to be removed from the project area. Adequate access to the streambank shaping for dump trucks and heavy equipment may be needed.

Construction –The limits of grading and disturbance should be clearly marked in the field, and the designer should be present at the site during all grading operations. The success of streambank shaping is highly dependent on the skills of the heavy equipment operators. The designer and equipment operators must clearly understand each other and the project's

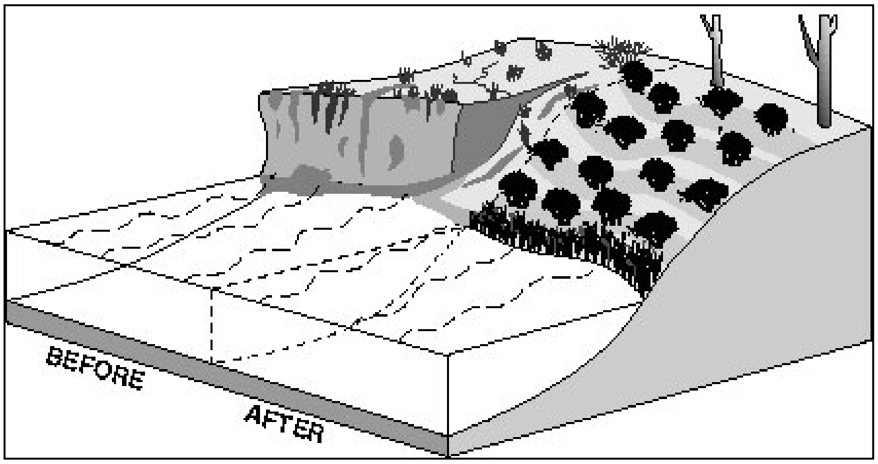


Figure 3: Before and after a streambank shaping project
Source: FISWRG, 1998

objectives. Erosion control practices should be installed along the toe of the streambank, prior to any grading. When grading is complete, streambanks should be re-vegetated with native trees, shrubs and ground cover, in accordance with the revegetation plan (see Profile Sheet R-15).

Hydro-seeding is the most efficient means to quickly establish a ground cover on relatively flat floodplain areas disturbed during construction operations. The newly shaped streambank, however, should be seeded by hand or mechanically seeded, with the seed tamped or rolled to ensure good soil contact. Erosion control fabric should be applied to lower bank areas exposed to streamflow (i.e., coir fiber, jute, straw). Additional planting can then be installed in accordance with the revegetation plans.

Maintenance/Monitoring – Newly-shaped streambanks should be monitored frequently during the first two weeks to ensure that adequate moisture is available for seed germination and growth. If not, supplemental watering must be provided. The streambanks should be inspected after the first significant storm event for erosion and soil loss. Any erosion should be immediately repaired.

Cost – The cost of streambank shaping depends on the volume of soil removed, and associated hauling and disposal costs. Typical grading costs can run from $5.00 to $15.00 per cubic yard. Project costs increase when the project site requires specialized equipment, access is difficult, or if sediment disposal sites are distant. In addition to grading costs, designers should consider revegetation and erosion control costs. Seeding costs can range from $0.16 to $1.65 (specialized seed mixes) per square yard. Erosion control fabric costs range from $3.00 to $10.00 per square yard, installed.

Further Resources

Useful guidance and specifications for bank shaping can be found at the following online resources:

Washington State Integrated Streambank Protection Guidelines.
http://www.wdfw.wa.gov/
(Bank Reshaping)

Stream Corridor Restoration: Principles, Processes, and Practices
http://www.usda.gov/stream_restoration/PDFFILES/APPENDIX.pdf

Water Related Best Management Practices in the Landscape - Stream System Protection, Restoration, and Reestablishment
http://abe.msstate.edu/csd/NRCS-BMPs/pdf/streams/bank/bankshaping.pdf

R-9

Stream Repair: Soft Bank Stabilization

COIR FIBER LOGS

Description

Coir fiber logs are a stream repair practice that provides toe protection for small urban streambanks. They are commercially made, biodegradable, erosion control products and go by many trade names, such as Biologs™, Koirlog™, BioD-rolls™, and Fiberschines. Coir fiber logs consist of tightly bound cylinders of coconut fiber (coir) held together by coir fiber netting. They are typically one foot in diameter and 10 to 20 feet long, although other lengths and diameters are available. Coir fiber logs are installed along the toe of the streambank to provide short-term deformable protection of the streambank toe The fiber log decays in two to five years, but roots from colonizing vegetation gradually replace the coir fiber and provide vegetative stabilization at the toe. Stream sediments deposited in the log also provide a good medium for plant growth. Coir fiber logs are an excellent method to provide short-term toe protection in streams where toe scour is not severe and riparian conditions are conducive to rapid plant growth (Figures 1 and 2).

Habitat Features Created – Coir fiber logs enhance habitat by stabilizing the streambank toe and fostering the growth of overhanging vegetation.

Feasibility

Coir fiber logs are placed along the toe of the streambank to provide an erosion-resistant planting medium for riparian vegetation. They are most appropriate for smaller, low gradient urban streams that are not rapidly incising or laterally adjusting. The logs are installed near the stream invert so they become saturated with water, which allows vegetation to be planted directly within them. Coir fiber logs appear natural and unobtrusive, and gradually decompose over a 2 to 5 year period, leaving the roots of colonizing vegetation to secure the toe of the streambank (Miller *et al*., 1998). Individual logs are relatively lightweight (e.g., a 10-foot roll weighs about 75 pounds), and can be installed with a minimum of site disturbance.

Figure 1: Coir fiber log prior to plant installation

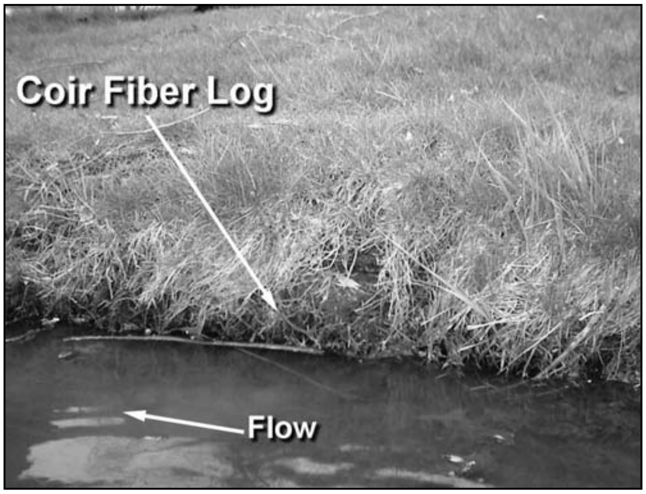


Figure 2: Vegetated coir fiber log installed along a low gradient stream

Coir fiber logs have very limited ability to prevent significant streambank toe scour. In streams that have the potential for significant scour, alternative streambank toe protection techniques should be used (Figure 3). Coir fiber rolls are also not recommended for actively degrading channels. In addition, coir fiber logs require sufficient sunlight to enable the growth of colonizing plants.

Implementation

Coir fiber rolls are installed by excavating a three to four-inch deep trench along the toe of the streambank. The coir fiber log is then placed in the trench so that the bottom and back of the log are in contact with the stream substrate and the toe of the streambank, respectively. Best plant survival occurs when the log is installed so that its top is above the baseflow level of the stream or the lower level of perennial vegetation, whichever is higher (Figure 4). If water depth is greater than log height, two fiber logs can be stacked so that the upper log is suitable for planting. Each successive length of log must be placed end to end with the next, using coir fiber or synthetic rope. The upstream end of the coir fiber log should always be inserted, or “keyed,” three to five feet into the streambank to prevent dislocation.

Once the coir fiber logs are placed in the stream, they can absorb up to 10 times their weight in water, which makes repositioning them difficult. Notched hardwood stakes are used to secure coir fiber logs and are partially driven into the substrate along the sides of the log at intervals specified by the manufacturer. Coir or nylon twine is woven between and around the notches of each stake, which is then driven flush with the top of the coir fiber log to firmly secure it to the streambed. The streambank above the coir fiber log can then be graded or laid back to the top of the log and stabilized with appropriate vegetation.

If erosion control fabric is needed to hold the upper bank, it should extend to the toe of the coir fiber log to provide a smooth and secure transition. Coir fiber logs can also be used in combination with mattresses and other upper streambank bioengineering practices (e.g., brush mattresses, live fascines, bank shaping). Planting of live rooted materials in the coir fiber logs should be delayed for at least a month to allow stream sediments to infiltrate the coir fiber in order to improve plant vigor and survival.

Maintenance/Monitoring – Coir fiber log installations should be inspected after the first significant storm to ensure that they are securely fastened to the streambed and bank. Once planted, vegetation should be checked periodically during the first growing season, and dead/dying plant materials should be replaced. The installations should also be inspected after the log decays to ensure that rooted vegetation can hold the bank.

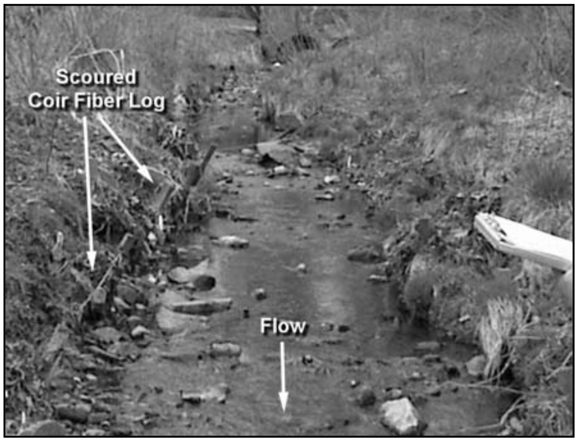


Figure 3: Coir fiber log has decayed without vegetative stabilization

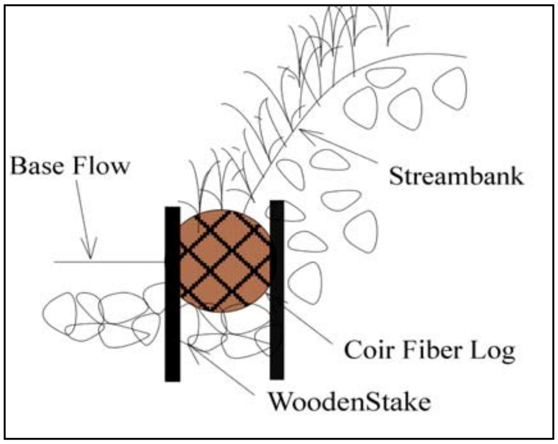


Figure 4: Cross-section view of coir fiber log installation

Cost – Reported unit costs to install coir fiber logs range $8.00 to $30.00 per linear foot, depending on the log diameter selected. Average costs are about $15.00 per linear foot.

Further Resources

Several design specifications for coir fiber logs can be accessed from the following websites:

Washington State Integrated Streambank Protection Guidelines
http://www.wdfw.wa.gov/
(Coir Logs)

Maryland Guidelines to Waterway Construction
http://www.mde.state.md.us/assets/document/wetlandswaterways/sec2-6.pdf

The Practical Streambank Bioengineering Guide for Arid and Semi-Arid Intermountain West
http://plant-materials.nrcs.usda.gov/pubs/idpmcpustguid-appA.pdf (fiberschines)

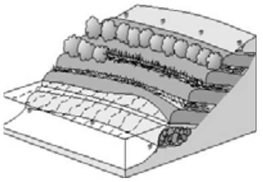
Coir Geotextile Roll and Wetland Plants for Streambank Erosion Control
http://www.wes.army.mil/el/emrrp/tnotes.html

Virginia Stream Restoration and Stabilization Best Management Practices Guide (natural fiber rolls)
http://www.dcra/state/va.us/sw/docs/streamguide.pdf

R-11

Stream Repair: Soft Bank Stabilization

SOIL LIFTS



Description

Soil lifts are a stream repair technique used to reconstruct a streambank using successive layers of soil wrapped or encapsulated within erosion control fabric. They are also known as reinforced soil, vegetated geogrids, or fabric-encapsulated soil. Each lift forms a terrace that sits atop the lift beneath it (Figure 1). The streambank soil and the height of the reconstructed streambank determine the number and height of the lifts. Vegetative cover is then established on the surface of each lift by one of three methods, direct seeding beneath the ECF, rooting plants directly through the lifts, or placing dormant cutting along the face of the lifts.

Habitat Features Created – Soil lifts indirectly enhance stream habitat through the creation of a stable streambank toe and reduced sedimentation from streambank erosion.

Figure 1: Soil lifts

Feasibility

Soil lifts are used to stabilize urban streambanks where structurally sound but deformable treatment is desired. Soil lifts avoid the potential drawbacks of traditional hard bank stabilization practices, such as boulder revetments. When used in combination with an effective toe protection technique, soil lifts can immediately stabilize streambanks and ultimately provide deformable vegetative stabilization over the long term. Soil lifts are a versatile streambank stabilization technique since they can reconstruct streambanks with slopes as steep as 1H:1V and banks as tall as 30 feet. Various types of ECF are available to encapsulate lifts (e.g., biodegradable, synthetic, woven, and non-woven). The choice of which ECF to use depends on streambank soils, the degree of protection required, and the potential for future erosion (see Profile Sheet R-10).

Soil lifts are applicable in most regions of the country, but plant materials used to provide vegetative stabilization should be adapted to local conditions.

Soil lifts must be combined with grade controls and toe protection in actively degrading streams. Streambank toe protection may not be needed to protect soil lifts on aggrading streams. In addition, the soils contained within the lifts must have sufficient fertility and texture to support plant growth, unless soil amendments are provided.

Implementation

A system of soil lifts typically consists of four components, as shown in Figure 2.

1. Toe protection
2. Gravel filter drain
3. Soil lifts
4. Vegetation

1. Toe Protection - Designers should first determine the potential depth of scour and then select an effective toe protection treatment to keep the lower streambank stable. Scour at the streambank toe will quickly undermine soil lifts further up the bank. As a general rule, toe protection should extend from the maximum expected depth of scour in the streambed up to the level of perennial vegetation on the streambank.

Streambank toe protection can be designed in two ways. The first is to design the toe so that it is essentially immobile at any flow (non-deformable). The second is to design the toe so that it is immobile until vegetative cover is established, but then becomes mobile during high flows thereafter (deformable). A deformable streambank toe allows natural channel migration to occur in the stream corridor, whereas a non-deformable hard toe prevents the stream from adjusting over time as watershed conditions change (Miller and Skidmore, 2000). Non-deformable structures are generally recommended when infrastructure and/or private property are significantly threatened by erosion.

Deformable streambank toe protection usually consists of rock wrapped within ECF that is sized to become mobile during the 10 to 25 year design storm flow event. The fabric helps reinforce and immobilize the rock at high flows until upper bank vegetation is established. At that point, the streambank toe will again be mobile and deformable.

2. Gravel Filter Drain - A gravel filter drain is a layer of gravel, installed beneath or behind the soil lifts that extend down to the streambank toe. The gravel filter drain allows water to drain out of the streambank and prevents high pore water pressure during rapid drawdown events common in urban watersheds. Rapid drawdown occurs when floodwaters recede rapidly, leaving saturated streambanks susceptible to slope failure.

3. Soil Lifts - Individual lifts can range from 0.5 to 1.5 feet high (Figure 2). The bank soil type to be encapsulated and the height of the streambank will determine the number and height of each soil lift. Nutrient poor, sandy soils can be problematic since they are unstable and seldom support dense or vigorous vegetation. When these soils are encountered, soil lifts should be amended with topsoil, compost or other soil amendments. Normally, a soil lift is encapsulated by two layers of coir fiber fabric; an outer layer of ECF netting reinforces the lift, while an inner layer of non-woven coir fiber is used to prevent loss of fine soil particles from within the lift.

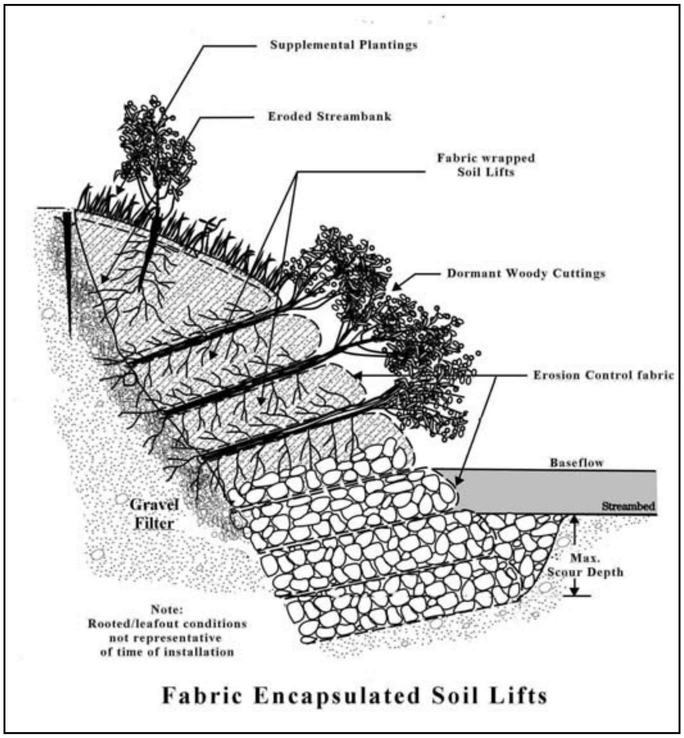


Figure 2: Cross-section of a streambank constructed of soil lifts
(Source: USDA NRCS)

4. Aggressive Revegetation – As the ECF degrades, the roots of the vegetation will provide structural reinforcement of the streambank. Consequently, an aggressive plan is needed to establish vegetative cover that accounts for soil fertility and moisture conditions (see Profile Sheet R-15). Seeding of native grasses beneath the ECF is recommended to provide initial rapid ground cover. Dormant cuttings of native riparian shrubs are often placed horizontally between each successive soil lift (using the same plant materials that are used for brush mattresses or live fascines, see Profile Sheets R-13 and R-14). Horizontal dormant plantings should be arranged at two to five cuttings per foot with the butt (basal) ends extending to the back of the excavated trench. They should be placed so that 75% of the cutting is covered by the next overlying soil lift. Care should be taken not to jeopardize the integrity of the ECF during planting operations. Species selected should generally mimic the native riparian community.

Construction – The construction of streambank soil lifts is a complicated undertaking and requires an experienced construction supervisor and crew. The steps below simply outline the process and should not be considered exhaustive.

1. Excavate a trench for the toe protection.
2. Install toe protection treatment.
3. Place a layer(s) of ECF over the toe protection and leave enough length channelward to wrap over the compacted soil of the lift. Top and bottom edges of fabric should be embedded a minimum of three feet.
4. Place soil on the fabric and compact.
5. Seed the compacted soil where it will be exposed to sunlight.
6. Wrap the fabric tightly over the compacted soil and stake the fabric at the back of the lift. Make sure that the upstream and downstream ends of the lift transition smoothly and are secure keyed into the existing streambank.
7. Place a layer of dormant cuttings on top of the lift and spread some topsoil over them.
8. Place another layer(s) of ECF on top of the cuttings and repeat steps 4 through 7 until the desired bank height is reached.
9. Transition the existing streambank into the uppermost soil lift, re-vegetate disturbed areas and install any supplemental plantings.

Maintenance/Monitoring – Monthly inspections should be made during the first growing season to ensure adequate vegetative establishment. Inspections may indicate the need for supplemental watering/irrigation, re-seeding, or the replacement of dead/dying plant materials. When properly constructed, soil lifts should not generally require much long-term maintenance.

Cost – Not much standardized cost data has been reported for soil lifts, because each application is often unique. Available unit costs for a one-foot tall soil lift ranges from $12 to $30 per linear foot.

Further Resources

The following resources can be consulted for more detail on the design and construction of soil lifts:

Washington State Integrated Streambank Protection Guidelines (soil reinforcement)
http://www.wdfw.wa.gov/

Engineering Field Handbook - Streambank and Shoreline Protection (vegetated geogrids)
http://www.nrcs.usda.gov/technical/ENG/efh.html

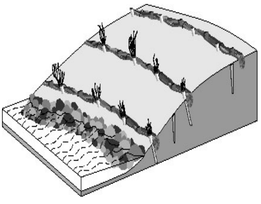
Stream Corridor Restoration: Principles, Processes, and Practices (vegetated geogrids)
http://www.usda.gov/stream_restoration/PDFFILES/APPENDIX.pdf

Virginia Stream Restoration and Stabilization Best Management Practices Guide (live soil lifts)
http://www.dcra/state/va.us/sw/docs/streamguide.pdf

R-13

Stream Repair: Soft Bank Stabilization

LIVE FASCINES



Description

Live fascines are a bioengineering technique used to stabilize eroding streambanks that consists of bundled dormant cuttings of willow, alder or poplar branches bound with either wire or twine. A typical fascine is about eight to ten feet long and six to ten inches in diameter, although they can be fashioned to almost any length and diameter needed to protect the eroding streambank site.

Fascines may be used as a toe protection technique along low gradient streams where erosion potential is low. In streams with higher erosion potential, fascines are restricted to higher portions of the streambank, and are located above or behind more resistant toe protection techniques, such as rootwad or boulder revetments (Figure 1).

Habitat Features Created - Live fascines do not directly enhance in-stream habitat, but do create a stable streambank with overhanging vegetation.

The typical application places fascines in shallow trenches along the streambank that is parallel to the stream. When installed correctly, dormant cuttings will quickly root and grow, adding structural stability and vegetative protection to the streambank, and preventing down slope erosion and rill formation. On taller streambanks, two or more parallel rows of fascines may be installed to stabilize the streambank. Live fascines will also provide several years of physical protection to the streambank since the dense bundles add roughness that dissipates the energy of erosive flows.

Live fascines utilize dormant cuttings that are harvested during the non-growing season and then installed early in the next growing season. Specific guidance on harvesting of dormant cuttings is provided in Profile Sheet R-12.

Feasibility

Live fascines alone cannot stabilize streambanks experiencing severe erosion, and should not be installed below the elevation where flow conditions prevent the establishment of perennial vegetation on the bank. Most riparian shrub species used in fascines require full or partial sun and are not suited to heavily-shaded stream corridors.

Regional Considerations – Woody species used for fascines should be obtained from local sources that are best adapted to local growing conditions. The Natural Resources Conservation Service Plant Materials Program offers excellent guidance on the regional suitability of various woody plants and the best times of year to install

Figure 1: Fascines installed behind a boulder revetment

fascines and can be found in the *Further Resources* section.

Implementation

When fascines are harvested, no more than one-third of the stem should be cut from any individual shrub. Terminal buds should be removed from the branches to promote lateral bud growth. Stem cuttings should be at least one-half inch in diameter, measured at the base of the stem. To ensure rooting success, cuttings should be harvested in late fall or winter and refrigerated until needed in spring.

Fascines are normally assembled by bundling a mix of branch sizes into eight to ten foot lengths that are roughly six to ten inches in diameter (although almost any length or diameter can be assembled to meet project needs). Bundles should be secured with twine or wire every 18 inches along their length.

Fascines should be placed in pond or stream water for several days before installation to initiate root growth.

Construction - Fascines should be installed as low on the streambank as practical, but they should not be submerged. On longer bank slopes, multiple rows of parallel fascines can be installed up the streambank, but only if soil moisture along the upper bank can support growth. On banks where conditions are drier, or in arid or semi-arid regions, live stakes that can reach down to the summer water table are a better alternative.

Individual fascines are installed in a shallow trench that is excavated parallel to the streambank. The trench should be deep enough so that two-thirds of each fascine lies below the soil surface. The fascines should overlap each other by one to two feet. The excavated soil should then be tamped down into the fascine filling the voids between cuttings to the greatest degree possible. Fascines should be secured with stakes (e.g., diagonally cut 2x4s) driven through the fascines at three to four foot intervals. Stakes should also be driven through the overlaps between fascines (Figure 2).

More often than not, fascines are installed above more robust toe protection measures, such as boulder revetments, coir fiber log, A-jacks, or lunkers (Figure 3). When installing fascines immediately above an A-jack or boulder revetment, place the erosion control fabric between the revetment and the fascine to ensure that soil is not lost through the revetment.

One of the preferred fascine applications is to install them immediately behind coir fiber logs along lower gradient streams. The coir fiber logs ensure protection and offer an excellent rooting medium for the fascines. As the coir fiber logs disintegrate over time, the roots of the cuttings will grow to replace them.

Maintenance/Monitoring - Little or no maintenance is required once fascines are established. Fascines should be inspected during the first growing season to ensure that they are still secure, and have adequate soil cover and moisture.

Cost – Reported unit cost for installation of live fascines ranges from $5 to $22 per linear foot, depending on the availability and cost of cuttings and local labor rates.

Figure 2: Fascines installed along a streambank

Figure 3: Fascines installed behind a coir fiber roll

Further Resources

Many regional and national references can be consulted on the design and installation of live fascines:

The Practical Streambank Bioengineering Guide Arid and Semi-Arid Intermountain West (fascines or willow wattles)
http://plant-materials.nrcs.usda.gov/pubs/idpmcpustguid-appA.pdf

Maryland Guidelines to Waterway Construction
http://www.mde.state.md.us/assets/document/wetlandswaterways/sec2-5.pdf

Washington State Integrated Streambank Protection Guidelines (woody plantings)
http://www.wdfw.wa.gov

USDA-NRCS Jamie L. Whitten Plant Materials Center
http://plant-materials.nrcs.usda.gov/mspmc/

The Natural Resources Conservation Service Plant Materials Program
http://plant-materials.nrcs.usda.gov/

Ohio Stream Management Guide (live fascines)
http://www.ohiodnr.com/water/pubs/fs_st/stfs14.pdf

Natural Resources Conservation Service. Engineering Field Manual. Stream and Shoreline Protection
http://www.nrcs.usda.gov/technical/ENG/efh.html

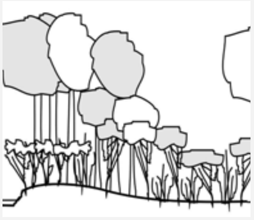
Live and Inert Fascine Streambank Erosion Control
http://www.wes.army.mil/el/emrrp/tnotes.html

Ontario Stream Rehabilitation Manual (fascines)
http://www.ontariostreams.on.ca/OSRM/toc.htm

R-15

Stream Repair: Soft Bank Stabilization

VEGETATION ESTABLISHMENT



Description

Establishing vigorous vegetative cover is a critical element of streambank stabilization. The streambank planting zone extends from the lower limit of perennial vegetation up to the top of the bank, and is periodically subject to inundation by erosive storm flows. The lower limit of perennial vegetation is controlled by more frequent, higher velocity storm flows. Perennial vegetation may survive down to the baseflow elevation of undeveloped streams. In urban streams, however, frequent storm flows and fluctuating water levels often create a vertical gap between the baseflow elevation and the lower limit of perennial vegetation. The gap is subject to erosion and usually stabilized with a toe protection practice. While plants themselves may not survive in the lower bank area, extended roots of herbaceous and woody plants may help stabilize the toe, as long as current velocities during storms are not severe.

Along small headwater streams with low streambanks, the entire streambank planting zone may only be a few feet wide and tall. By contrast, the planting zone may extend from ten to 30 feet in larger streams, supporting several different plant communities based on the frequency of inundation, soil type and bank angle. Practices for the streambank planting zone are distinguished from those of the riparian planting zone, which extends from the top of bank and across the stream corridor. Site preparation and planting practices for the riparian zone are described in Profile Sheets SP-1 to SP-4 and F-5 to F-8, contained in Manual 5.

Habitat Features Created - Streambank plantings can provide multiple benefits, including stream shading, a source of leaf litter and large woody debris, flood attenuation, pollutant removal, and wildlife habitat.

Application

There are two general phases to establish streambank vegetation. The first phase seeks to rapidly seed the exposed streambank to establish cover to prevent erosion and ensure streambank stability. Biodegradable erosion control fabrics (ECF) are often used to reinforce the soil until the grass seed germinates (see Profile Sheet R-10). Seed used for rapid bank stabilization consists of a mixture of native riparian grasses and fast germinating annual grass species. Annual rye grain is often used along streambanks since it can be seeded in the fall, winter or spring and will provide good stability. Annual grasses will not persist after the first season, allowing perennial species to take over. Make sure to avoid seeding perennial rye grass. The second phase seeks to establish woody vegetation on upper portions of the bank. The deeper roots of trees and shrubs consolidate bank soils and prevent erosion. Either dormant cuttings or live materials can be used to establish woody vegetation.

Dormant cuttings, such as live stakes and fascines (Profile Sheets R-12 and R-13) are typically planted at the same time as the ECF is installed. The planting of bare root or container grown plants is usually delayed until grasses have initially stabilized streambank soils. Live plant materials are much more expensive than seed and there is a greater chance of live plant survival once initial soil stabilization is achieved. In addition, cutting the ECF to install live plant materials disturbs the integrity of the fabric and should be avoided until a vigorous grass cover has been established.

The installation of live stakes, fascines, and erosion control fabrics are described in Profile Sheets R-10, R-12, R-13, and R-14. The remainder of this profile sheet focuses on how to establish native woody vegetation after the streambank is stabilized.

Dormant plant materials must be installed either before or very early in the growing season. Live plants also have a longer planting window and can be planted throughout the growing season in most locations, although supplemental watering may be required. Plantings should mimic the natural vegetation found along the streambank, with the goal of achieving a mature, self-sustaining plant community.

Implementation

The characteristics of the streambank influence density, location and species of vegetation planted. Often, coarser sediments (i.e., sands, small gravel) are deposited close to the stream channel, whereas finer silts and clays are deposited further away from the stream. This tends to form low, natural levees along the top of the streambank. As a result, the streambank planting zone often has the driest and sandiest soils, with soil conditions becoming wetter with increasing distance from the stream (Figure 1). Upland species often become established along the top of the streambank with riparian or wetland species occurring lower down along the streambank.

A planting plan should be developed for every streambank stabilization project that contains the following minimum elements:

- Planting schedule
- Planting material handling and storage guidelines
- Site preparation requirements
- Project maintenance and monitoring schedule
- Number, location and bank elevation of plant species to be installed
- Location of vegetation to be preserved and sensitive resource areas
- Access points to the site

Plant Species – A diverse mix of plant species should be chosen that is typical of species found along streams in the region. Important plant characteristics include tolerance of inundation and drought, growth form (i.e., grass, herb, shrub, tree), rate of growth, resistance to disease, and benefit to wildlife. Plants species should be appropriate for local climate and rainfall, as well as site conditions such as soils, sun exposure and moisture. The *Further Resources* section has several websites that offer helpful guidance on plant selection.

Plant Materials - Planting materials can include seed, bare root, and container grown stock. Each type of plant material has advantages and disadvantages (Table 1). Plants should be grown locally or obtained from a local source to ensure adaptation to local conditions. If purchased, inspect the plant materials upon arrival to ensure

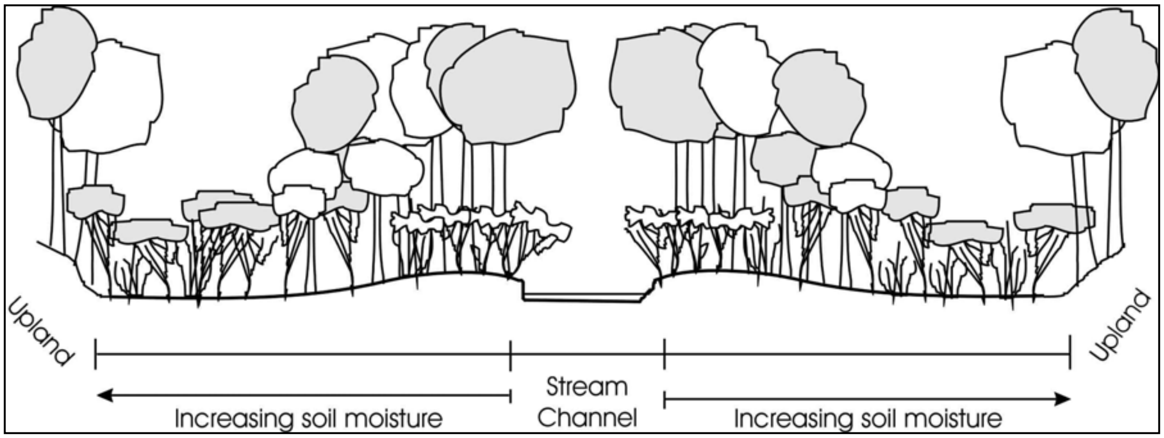


Figure 1: Soil moisture gradient along a stream corridor

Type of Plant Material	Advantages	Disadvantages
Seeds	• Most inexpensive	• Low survival rates • Slowest to establish
Bare root	• Inexpensive • Readily available	• Low survival rates • Slow to establish • Limited planting window • High maintenance
Container-grown trees and shrubs (one to seven gallons)	• Can out compete invasives • Low maintenance • High survival rates • Quick to establish	• Limited availability • Moderate to high cost • Limited availability

viability. Plant materials may require storage for a period of time between delivery and installation. Storage conditions prior to installation must be appropriate for each type of plant material and should be specified on the planting plan. The planting density should be based on individual species requirements, but should be clustered or grouped, where possible.

Maintenance – Maintenance requirements may include supplemental watering during establishment, weed/invasive species control, replacement of dead/diseased materials, and supplemental plantings. Indeed, designers should plan and budget for extensive maintenance of the streambank planting zone during the first several growing seasons after installation.

Special Considerations – The streambank planting zone can be a difficult environment to produce the desired vegetative community. Many practitioners have reported poor plant survival or competition from invasive plants at many urban streambank vegetation sites (UCMT, 2004, Brown, 2000). Some special maintenance considerations for the urban streambank planting zone are offered below:

Invasive Plant Species - Invasive plant species are commonly found in urban riparian areas and may quickly out compete newly-planted native species if they are not effectively controlled. In many cases, soil disturbance and light exposure during stream repair construction create optimal conditions for invasive species to invade the site. Even if invasive plants are removed from the planting site, seeds from adjacent land can soon re-infest the site. Methods to control invasive species include mechanical removal, herbicides, and biological controls (See Profile Sheet SP-2 in Manual 5). From a design standpoint, the best planting strategy is to rapidly create dense and vigorous woody vegetation that can shade out invasives, and to plan and budget for invasive plant removal should this strategy fail.

Beavers - Beavers can cause damage to existing or newly planted trees in riparian areas by flooding or removing tree bark (Kwon, 1999). If beavers are present in the project reach, several options can prevent damage to trees:

- Deer Repellent: The unpleasant odor may drive beavers to move to a new site
- Tree Guards: A three-foot tall collar of hardware cloth or heavy wire mesh can be installed around the base of newly planted trees. While it limits damage to bark, it may be too expensive to use for a long streambank planting area.
- Water level control devices: Install a pipe under the beaver dam to drain the pond (Kwon, 1999)
- Trapping and relocation

Deer - Deer often browse on newly installed vegetation, and can cause extensive plant mortality when deer populations are high in the urban stream corridors. A common indicator of overbrowsing is a prominent browse line, where no green vegetation exists within four to five feet of the ground. Several options exist to prevent deer as well as some rodents from damaging newly planted materials:

- Deer repellent
- Deer-resistant species – select and plant tree species that are unpalatable to deer
- Fencing – install a ten-foot tall wire fence around entire planting area; effective but expensive
- Population control methods
- Tree shelters – plastic tubes are an effective method to protect trees from deer browsing

Entrenched Streams and the Water Table – Channel incision in many urban streams creates entrenched channels with steep and tall banks. Riparian vegetation in these streams is disconnected from the water table and more upland species are favored (Groffman *et al.*, 2003). Thus, even though plants in the upper bank zone are close to the stream, they may experience poor soil moisture conditions, and grow more slowly or have poor survival rates. In some cases, irrigation may be needed to initially sustain fast rates of growth for woody vegetation. Streambank irrigation techniques are described in Fischenich (2001b).

Further Resources

The following resources present guidance on selecting the most appropriate plant species and practices for the streambank planting zone:

USDA Plants Database
http://plants.usda.gov/cgi_bin/topics.cgi?earl=fact_sheet.cgi

Lady Bird Johnson Native Plant Guide
www.enature.com/guides/select_lbjnative.asp

USDA Plant Hardiness Zone Map
http://www.usna.usda.gov/Hardzone/ushzmap.html

NRCS Plant Materials Program
http://plant-materials.nrcs.usda/gov/

Tennessee Valley Authority Banks and Buffer Software
http://www.tva.gov/river/landandshore/stabilization/websites/htm

Maryland Riparian Forest Buffer Design and Establishment Guidelines
http://www.agnr.umd.edu/MCE/Publications/publication.cfm?ID=13

NRCS Engineering Field Manual Stream and Shoreline Protection
http://www.nrcs.usda.gov/technical/ENG/efh.html

Landscaping Considerations for Urban Stream Restoration Projects
http://www.wes.army.mil/el/emrrp/tnotes.html

California Salmonid Stream Habitat Restoration Manual, Part XI: Riparian Habitat Restoration
http://www.dfg.ca.gov/nafwb/manual.html

R-19

Stream Repair: Grade Control

ROCK CROSS VANE

Description

A rock cross vane (RCV) is similar to the rock vortex weir, but differs in that the rocks barely extend above the stream invert. The RCV consists of a rock sill located perpendicular to stream flow that is situated at the invert elevation of the stream channel (Figure 1). The two arms of the sill extend downstream, rising in elevation until they meet the streambank at bankfull height. The low profile of a RCV makes it less vulnerable to scouring and upstream sediment deposition. The RCV is generally used to provide grade control, narrow the baseflow channel, and reduce local bank erosion. RCVs are often located at the top and bottom of meander bends to establish invert elevations for pool/riffle formation (Figure 2).

Habitat Features Created – Rock cross vanes have a modest potential to enhance in-stream habitat through the maintenance of stream grade and the enhancement of riffle habitats.

Feasibility

RCVs are most appropriate in low to moderate gradient cobble or gravel bed streams and should be avoided in sand-bed streams. While RCVs provide grade control, they generally cannot stop a significant knickpoint from migrating upstream. In these situations, a step pool or other hard grade control structure may be needed. Construction requires access by heavy equipment and adequate room to stockpile materials. Construction may also require dewatering, flow diversion, or cofferdams.

Implementation

RCVs consist of a low weir section with two adjacent arms extending downstream into the streambanks that rise to bankfull elevation of the stream (Figure 3). Care must be taken to ensure that the arms are keyed far enough into the streambanks to prevent outflanking during high flows.

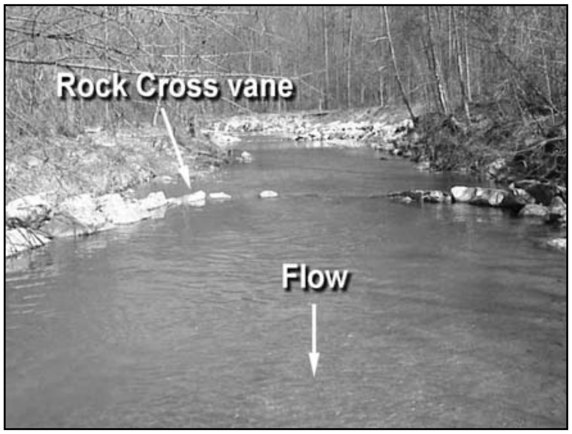


Figure 1: A well designed rock cross vane

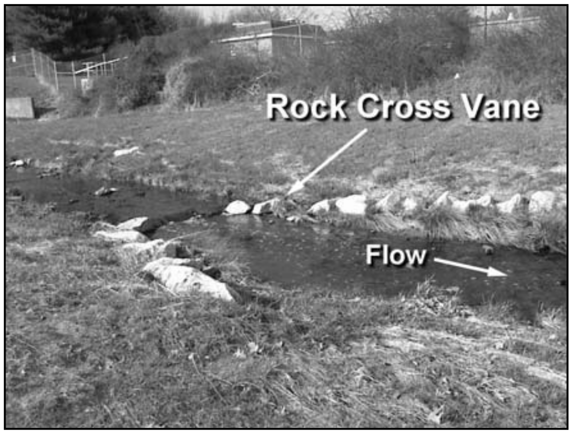


Figure 2: A rock cross vane used to establish stream invert

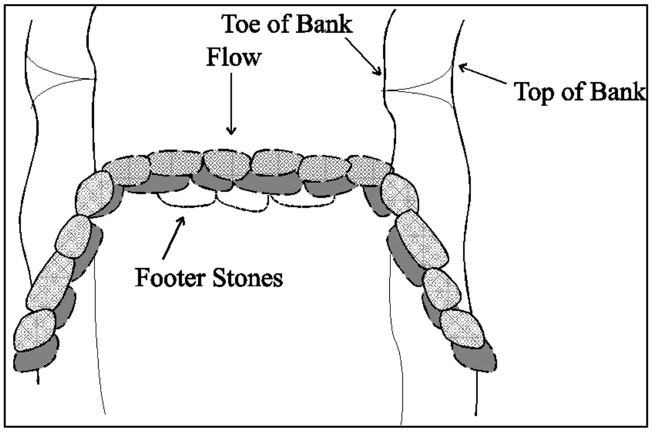


Figure 3: Plan view of a rock cross vane

Construction – RCVs are constructed of large angular rocks that are typically two to three feet in diameter. Each rock must be heavy enough to remain immobile during the highest flows expected for the streambed.

The sequence of construction starts with a rock sill that is formed by excavating a trench perpendicular to stream flow in the center third or half of the stream. As a general rule, the trench should be two or three times deeper than the rocks are high (depending on the number of rock footer courses) and just wide enough to accommodate the rocks. Large, flat rectangular rocks are then placed end to end in the trench so that they are touching each other. One or two stone footer courses are usually used, depending on the width of the channel and the erosive capacity of the stream (Figure 4). Once the first footer course is installed, the trench is then extended upstream of the course so that a second layer of rocks can be placed in a shingle formation (e.g., half on the streambed and half of the rock overlapping rock course).
The trench needs to be extended the entire width of the bankfull channel in the form of an inverted “U” with the arms at a 20 to 30 degree angle to the streambank. The U-shaped trench is then extended upstream once again, and a third set of rocks is placed so that it overlaps the second course. Once again, a shingle pattern is used such that about a third of each rock is on the streambeds and two-thirds overlaps (See Figure 3 above). The tops should be even or slightly above the desired stream invert within the baseflow channel of the stream (Note: only two courses of rock may be needed in smaller streams).

The RCV’s arms should rise to bankfull elevation and be anchored several feet into the streambank to prevent outflanking. The number of courses and the size of the stone will depend on the size of the stream, the potential for scouring, and the type of stream substrate (Castro and Sampson, 2001). Geotextile liners should be placed upstream of the vane to prevent fine sediments from piping through the rock structure.

Maintenance/Monitoring - If the RCV is properly constructed, little maintenance is needed. Each RCV should be inspected after the first large storm event to check for rock movement, and after the first growing season to check for adequate vegetative stabilization along the streambanks.

Cost - Average unit costs to install a single RCV range from $1,200 to $1,700, although they can increase to $4,000 to $5,000 in wider streams. These were derived from four different sources and do not reflect costs related to design, project access, mobilization and complex flow diversion or dewatering techniques during construction.

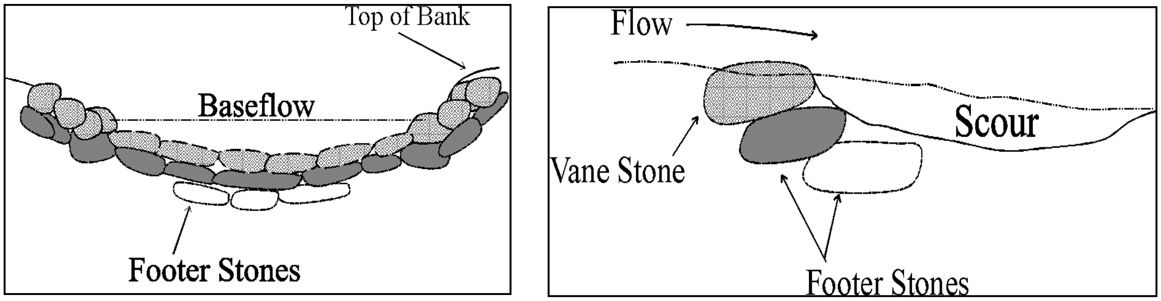


Figure 4: RCV profile (a) and Cross-section (b)

Further Resources

Additional guidance on design and construction of rock cross vanes can be found in the following sources:

Maryland Guidelines to Waterway Construction
http://www.mde.state.md.us/assets/document/wetlandswaterways/sec3-8.pdf

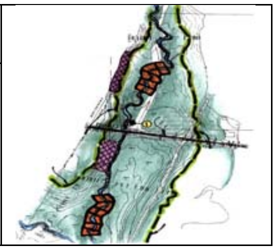
North Carolina Stream Restoration: A Natural Channel Design Handbook (rock cross vane)
http://www.bae.ncsu.edu/programs/extension/wqg/sri/stream_rest_guidebook/guidebook.html

Design of Stream Barbs (Technical Note 12)
http://www.id.nrcs.usda.gov/technical/engineering/

CR-31

Comprehensive Stream Repair Applications

COMBINATIONS OF SIMPLE PRACTICES



Description

Combinations of individual stream repair practices are frequently required to achieve specific restoration objectives without making major changes to the planform of the urban stream channel. The comprehensive approach is distinctly more limited in scope than either channel re-design (CR-32) or de-channelization (CR-33), since it does not involve the complete re-construction of the stream channel. The designer works with existing stream channel morphology, making relatively minor changes to its grade, cross-section and planform to achieve the intended design objective. Generally, this approach works best in older urban stream channels that have achieved some measure of channel stability in terms of grade and planform, but still have specific habitat or fishery impairments. Combinations of simple practices should be used with caution on actively adjusting streams that have not yet evolved into a more stable morphology.

Several examples of this approach have been utilized across the country (Galli, 1999; Goldsmith *et al*., 1998; and Gustav, 1994), and a typical layout is presented in Figure 1. Table 1 presents guidance on how individual stream repair practices can be combined together to achieve specific restoration objectives. It should be kept in mind that no two urban stream situations are exactly alike, and each project should be deigned based upon local stream assessment studies and analysis of subwatershed conditions. The combination approach should always be integrated with other subwatershed and stream corridor practices such as storm water retrofits, riparian management, discharge prevention and pollution source controls, as shown in Table 2.

Implementation

When stream repair practices are combined, each individual practice should be evaluated in relationship to other upstream or downstream practices so they effectively work together as a system. Locating practices haphazardly or too densely may cause individual practices to interfere with each other, and jeopardize the project as a whole.

Most combination projects require extensive stream and subwatershed data to support the design process (see Chapter 2). It is generally recommended that an interdisciplinary team of geomorphologists, engineers, hydrologists, biologists and surveyors design the project. The following information is generally required to support design:

- Determination of current channel adjustment process
- Hydraulic modeling of shear stress on bed and banks
- Expected depth of scour for the bed and banks
- Accurate mapping of all infrastructure and utilities within and adjacent to the stream channel
- A detailed topographic survey of the stream including longitudinal and cross-sectional profiles of the project reach, and adjacent upstream and downstream reaches
- Streambed material sizes and distribution
- Geotechnical data for streambank soils and a plant inventory
- Rock sizing calculations so that structures remain immobile during design flows
- Fish, habitat and/or passage surveys, if biological restoration objectives are pursued

Designers should always anticipate future increases in channel cross-sectional area and decreases in channel elevation, if significant development has recently occurred or is projected to occur in the upstream subwatershed. Failure to account for future increases in storm flows and sediment loads may lead to the failure of individual stream repair practices, and possibly the entire project (Brown, 2000).

A large number of potential combinations of stream repair practices exist, but the final selections should be assessed in terms of their primary intended function. For example, the need for grade control should be established before selecting a specific grade control practice. Once the design need for a practice type is established, the most appropriate stream repair practice(s) can be selected using the comparative matrices presented in Chapter 3.

Adjacent practices should then be analyzed for possible negative interactions. For example, hard bank stabilization practices may increase downstream flow velocities during storm events, which may warrant further grade control practices, even if they were not originally deemed necessary. Flow deflection practices

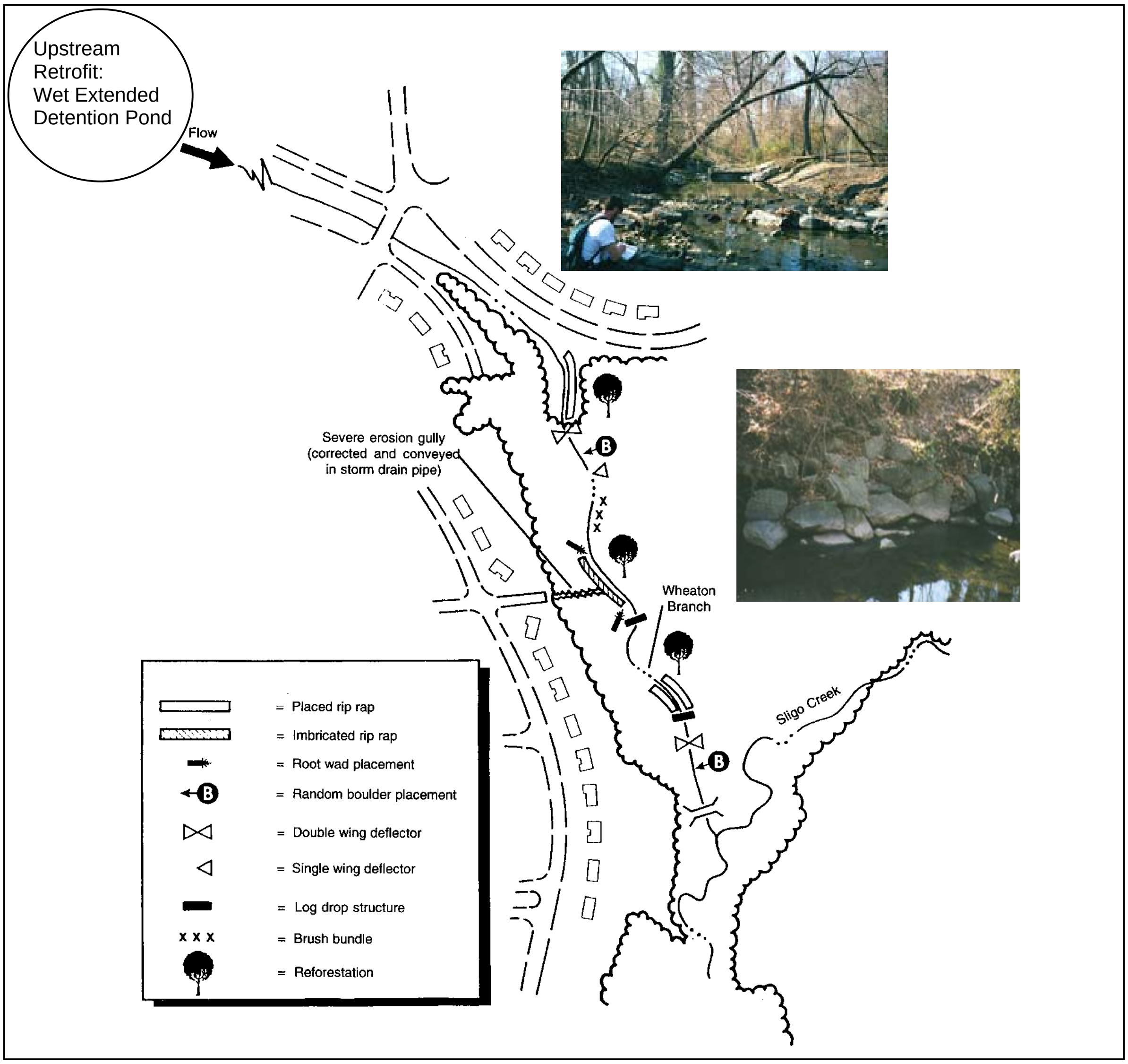


Figure 1: Example of Combination of Stream Repair Practices: Wheaton Branch, MD

may increase erosion on the opposite bank, making bank stabilization necessary. Each practice also has a zone of influence on the channel both up and downstream. Placing practices too close together may impair overall project function (Brown, 2000).

Table 1: Combinations of Individual Stream Repair Practices to Meet Design Objectives

Repair Practice	Naturalize stream corridor	Protect infra-structure	Prevent bank erosion	Expand stream network	Improve fish passage	Improve fishery habitat	Natural channel design	Recover biological diversity
Hard Bank Stabilization Practices								
Boulder revetments	⦿	●	●	○	×	×	○	×
Rootwad revetments	○	●	●	○	×	⦿	⦿	⦿
Imbricated rip-rap	⦿	●	●	○	×	⦿	○	○
A-jacks	⦿	⦿	●	○	×	×	○	○
Live cribwalls	○	⦿	●	○	×	×	○	○
Soft Bank Stabilization Practices								
Streambank shaping	⦿	⦿	●	○	×	○	●	⦿
Coir fiber logs	○	○	●	○	×	○	●	⦿
Erosion control fabrics	○	●	●	○	×	×	●	⦿
Soil lifts	⦿	●	●	○	×	○	●	⦿
Live stakes	⦿	⦿	●	○	×	○	●	⦿
Live fascines	○	⦿	●	○	×	○	⦿	⦿
Brush mattresses	○	⦿	●	○	×	○	⦿	⦿
Vegetation establishment	●	●	●	○	×	⦿	●	●
Flow Deflection Practices								
Wing deflectors	⦿	×	×	×	○	●	⦿	●
Rock or Log Vanes	⦿	⦿	⦿	×	×	●	⦿	⦿
Grade Control Practices								
Rock vortex weirs	⦿	⦿	⦿	○	○	●	●	⦿
Rock cross vanes	⦿	⦿	⦿	○	○	⦿	⦿	⦿
Step pools	⦿	⦿	⦿	⦿	⦿	○	⦿	⦿
V-log drops	⦿	⦿	⦿	○	○	⦿	⦿	⦿
In-stream Habitat Practices								
Lunkers	○	×	×	×	○	●	○	⦿
LWD placement	○	○	⦿	×	○	●	⦿	●
Boulder clusters	○	×	×	×	○	●	○	⦿
Baseflow enhancement	○	×	×	⦿	⦿	●	⦿	⦿
Flow Diversion Practices								
Parallel pipes	×	×	⦿	×	×	○	×	○
Stream daylighting	⦿	×	×	●	⦿	⦿	⦿	⦿
Fish Passage Practices								
Culvert modification	○	×	×	●	●	⦿	○	⦿
Culvert replacement	○	●	×	●	●	⦿	○	⦿
Devices to pass fish	○	×	×	●	●	⦿	○	⦿
Comprehensive Repair Applications								
Combinations	●	●	●	●	●	●	●	●
Channel Redesign	⦿	○	●	⦿	⦿	⦿	●	●
De-Channelization	⦿	○	⦿	●	●	●	●	●

Key ● *primary practice to meet design objective*
⦿ *supplemental practice to achieve design objective*
○ *occasionally used to meet design objective*
× *rarely used to meet design objective*

Table 2: Other Subwatershed Practices that Support Specific Stream Repair Objectives

Stream Repair Practice	Naturalize stream corridor	Protect infra-structure	Prevent bank erosion	Expand stream network	Increase fish passage	Improve fishery habitat	Achieve natural channel design	Recover diversity and function
Storm Water Retrofits	○	◉	●	◉	○	●	●	●
Riparian Reforestation	●	○	●	●	◉	●	●	●
Discharge Prevention	●	●	○	◉	◉	●	◉	●
Pollution Source Controls	◉	○	◉	◉	◉	◉	◉	●
Watershed Forestry	◉	○	●	◉	◉	●	●	●

Key: ● *essential to meet objective*
◉ *useful in meeting objective*
○ *rarely used to meet objective*

Further Resources

To date, there has been no published material to guide designers on how to effectively combine stream repair practices to meet the desired subwatershed objectives. Often, the selection, location, and interaction of stream repair practices are a matter of profession judgment and prior experience.