ADDRESSING STREAMBANK EROSION

This chapter addresses common project types and technical approaches for addressing streambank erosion through restoration and bank stabilization. These methods include bioengineering using native materials and revegetation as well as and more rigid structural measures. Before taking any of these actions, consider the underlying cause of erosion before you plan to address it. When looking at channel stability, an eroding stream bank is usually the symptom, not the process that should be considered. River systems respond to changes in the environment, including climate and land use. If imposed stresses (e.g., grazing pressure, channelization, etc.) can be managed or relieved, natural recovery is possible without a potentially costly intervention.

This chapter emphasizes a range of bioengineering/vegetative restoration methods, but also includes more rigid structural techniques for bank stabilization. Activities impacting the bed or bank will require permitting and should only be done in consultation with professionals. Landowners are encouraged to choose the methods that are least impactful to stream processes. These are often less expensive and require less permitting, while fitting within the local geomorphic, ecological, and social context of the landscape.

Contents

Selected methods need to be balanced with risks, cost, and potential impacts inherent with each of these techniques. The expertise of a qualified professional can assist greatly in the selection of appropriate methods. Additional guidance can be found here:

Cramer, M., K. Bates, D. E. Miller, K. Boyd, L. Fotherby, P. Skidmore, and T. Hoitsma. 2002. Integrated Streambank Protection Guidelines. Washington State Aquatic Habitat Guidelines Program, Olympia, WA.

NRCS (National Resources Conservation Service). 2007. Stream Restoration Design: National engineering handbook, part 654. U.S. Dept. Agriculture, NRCS, Washington, DC.

Saldi-Caromile, K., K. Bates, P. Skidmore, J. Barenti, D. Pineo. 2004. Stream Habitat Restoration Guidelines: Final Draft. Co-published by the Washington Departments of Fish and Wildlife and Ecology and the U.S. Fish and Wildlife Service. Olympia, Washington.

Wheaton J.M., S.N. Bennett, S. Shahverdian, J. Maestas. 2019. Low-Tech Process-Based Restoration of Riverscapes: Design Manual. Version 1.0. Utah State University Wheaton Ecogeomorphology & Topographic Analysis Lab. Logan, UT.

Yochum, Steven E. 2017. Guidance for Stream Restoration. U.S. Department of Agriculture, Forest Service, National Stream & Aquatic Ecology Center, Technical Note TN-102.3. Fort Collins, CO.

PROJECT PLANNING & DESIGN

Project planning and design must consider stream function at different scales for the long-term success, of a project. The larger context of watershed processes and adjustments (Chapter 2) provides an understanding of how projects will function and their effects at the watershed level.

The scope of planning and design varies with the scale and extent of issues being addressed. It is important to consider the project objectives and whether the proposed solution will help meet those objectives while considering impacts to overall stream function. More complex issues will likely require consultation with a professional hydrologist or engineer and relevant permitting entities.

Within the watershed, reach-level processes include smaller scale channel functions such as local planform, profile, cross-sections, sediment transport, scour and fill, and land use influences. Reach level information provides context to design and implement projects that are consistent with natural river function.

Design Approaches

The most successful project designs include an understanding of stream morphology and processes combined with bioengineering techniques to promote natural river function. Numerous approaches to river restoration and project design exist. Designs include empirical, analytical hydraulics, analogue/reference reach, and hybrid methods such as the geomorphic natural channel design approach.

At the watershed and reach level, tools such as RiverRAT (River Restoration Analysis Tool) offer a process to develop projects with ecological and river function in mind. Although it is not a site-specific design methodology, RiverRAT provides a planning, assessment, and project review tool for projects. A detailed diagram of the RiverRAT process and design considerations are in Appendix 2.

CAUTION

- Look at the big picture and understand the problem before you plan to fix it (eroding stream banks are usually the symptom, not the underlying process or problem to be considered)
- Consult the local Conservation District and all relevant permitting entities early in the process to avoid time consuming and costly delays
- Consider alternatives that are appropriate to the landscape setting and will have the least impact on resources
- Consider the relative cost and likely long-term ouctomes from selected alternative
- Consider adverse consequences that restricting lateral bank movement can have to channel function and re-establishment of long-term channel stability
- Consider whether a costly intervention results in a better long term outcome for the stream and/or the landowner

STREAM CHANNEL PROCESSES - SUMMARY

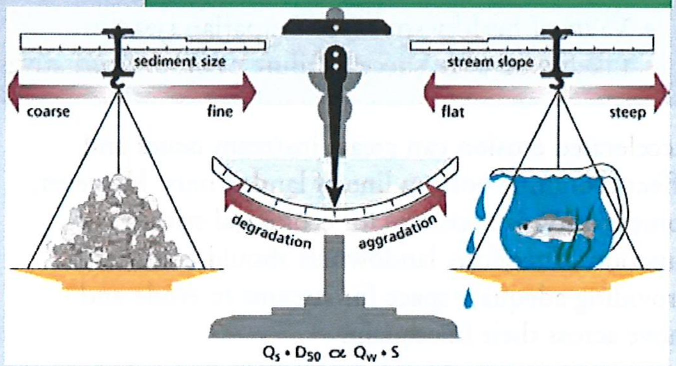
Factors in Channel Form and Process

Identifying the cause and solutions for bank instability can be relatively straightforward, or extremely difficult. Understanding basic concepts of stream form and function (Chapter 2) is necessary in evaluating a potential project. When in doubt, professional advice is recommended before beginning a project on unstable streams.

Basic factors to consider:

- Channel type (Appendix 1)
- Condition of riparian vegetation
- Adjacent land management or objects
- Aggrading or degrading conditions
- Lateral movement (size of depositional bar and vegetation gives good indication of rate of movement)
- Relative condition of upstream and downstream reaches

REMEMBER LANE'S BALANCE



Consider Channel Process before Channel Project

Understanding the underlying causes of bank instability is essential to selecting an effective bank treatment. In addition to examining upstream and downstream conditions, channel classification, aerial photos, and historical accounts can be helpful for interpreting channel process. An eroding bank is often the symptom of larger channel instability in the stream system. Stabilizing an eroding bank with natural or engineered materials often does not address the underlying cause of bank erosion. Extensive bank stabilization in channels undergoing certain types of change can degrade channel stability by constraining the channel from making needed adjustments. It may also result in a higher risk of failure.

Relevant questions to ask (and answer):

- Is instability systemic or localized?
- Is bank instability only lateral (side to side), or is the stream adjusting vertically?
- Is instability accelerated or natural?
- Does adjoining land use or disturbance play a role?

Examples of factors common with localized erosion are:

- Weak banks due to lack of vegetation or conversion from shrub to grass
- Scour associated with channel obstructions (ice, structures, slumping, or bridge abutments)
- Extreme events (icing, peak flows, tree blowdown)
- Channel aggradation upstream of undersized structures (e.g., culverts)

Example causes of large scale, systemic-type erosion include:

- Channel straightening
- Highway and railroad encroachment
- Extensive diking
- Inherent, large-scale watershed processes
- Extensive removal of vegetation in the watershed
- Mining

PASSIVE RESTORATION - THE NO ACTION ALTERNATIVE

Factors to consider before taking action

- Streambanks naturally erode and move across their floodplain (Chapter 2)
- Long-term goals for managing the land
- Consequences of not taking any action
- Cost of stablization or restoration against the value of the land that may be lost to erosion
- Value of healthy stream and riparian systems
- Likelihood of of success/failure of other alternatives

Accelerated erosion can create instream issues and affect economic bottom line of landowners. However, some erosion is necessary for ecological stream function. Therefore, landowners should consider providing adequate space for streams to erode and move across their floodplain.

Streams and riparian areas are resilient to some level of disturbance. Once the disturbance has been eliminated, vegetation will begin to recover over the course of a few years providing long term bank stabilization. This may take longer and result in some continued bank erosion and loss of land.

In order to restore passively to pre-disturbance conditions, a stream **must** have access to its floodplain at regularly recurring intervals and seed or root sources for revegetation.

Excluding surrounding land use and providing a buffer for this stream to move will reduce impacts to the stream and landuse operations.

Promoting natural recovery of native wetland and woody riparian plants is much less expensive than planting the equivalent nursery stock.

Landowner Considerations

- Distinguishing between change that falls within the range of natural variability and adverse impacts from land use is important in deciding if and how to intervene or compensate for channel response
- Rivers take care of themselves, and most channels don't need "fixing"
- Land use should be considered carefully
- If people are part of the problem, should they be part of the solution?
- Seek advice from Conservation Districts, agency staff, or qualified professionals.

RIPARIAN MANAGEMENT

Historical and ongoing land management are major sources of streambank instability and erosion throughout Montana. Deep rooted woody vegetation that lined stream corridors was removed to provide increased forage for domestic livestock and acreage for crop production. Over-utilization of riparian areas for grazing increases bank trampling and prevents vegetation from regenerating.

Producers are recognizing the value of riparian areas for their operations. Maintaining a riparian buffer on cropped fields reduces land lost to streambank erosion. Careful management of livestock with fencing or modified grazing schemes can improve and maintain the health of riparian areas and benefits they provide.

Considerations for grazing in riparian areas:
- Incorporate into overall grazing management
- Limit duration of livestock in riparian area
- Ensure adequate rest and vegetation regrowth
- Consider season and frequency of use

For more information on grazing methods and available resources, contact your local NRCS office.

One side of stream has not been grazed for 40 years and maintains deep-rooted woody vegetation.

Tilling up to the streambank reduces stability. Erosion is accelerated, particularly on an outside meander bend. Consider the value of arable land against long-term consequences and solutions. A 50 foot buffer along 1,000 feet of stream is 1.15 acres.

BENEFITS

- Low cost and low risk - mitigates against future needs to restore or stabilize streambanks
- Improved streambank stability and water quality
- Grants and cost share available from state and federal agencies to initiate riparian BMPs
- Fencing typically costs between $1to $5 per lineal foot
- Riparian pastures can provide access to quality forage during times less likely to impact stream function
- Willow stands provide refuge for spring calves

CAUTION

- Ensure fencing provides enough room to allow natural channel migration
- Restoring natural conditions takes time
- Recovery of riparian vegetation may take years
- Restabilization of streambanks and restored channel function may take decades

GRAZING MANAGEMENT - WATER GAPS and HARDENED CROSSINGS

Reducing livestock access to riparian areas has challenges, including ensuring access to drinking water and the land across the stream. This is best accomplished through off-stream watering tanks, water gaps, and hardened stream crossings that minimize disturbance to the streambank and channel.

Considerations for water gaps and hardened stream crossings:

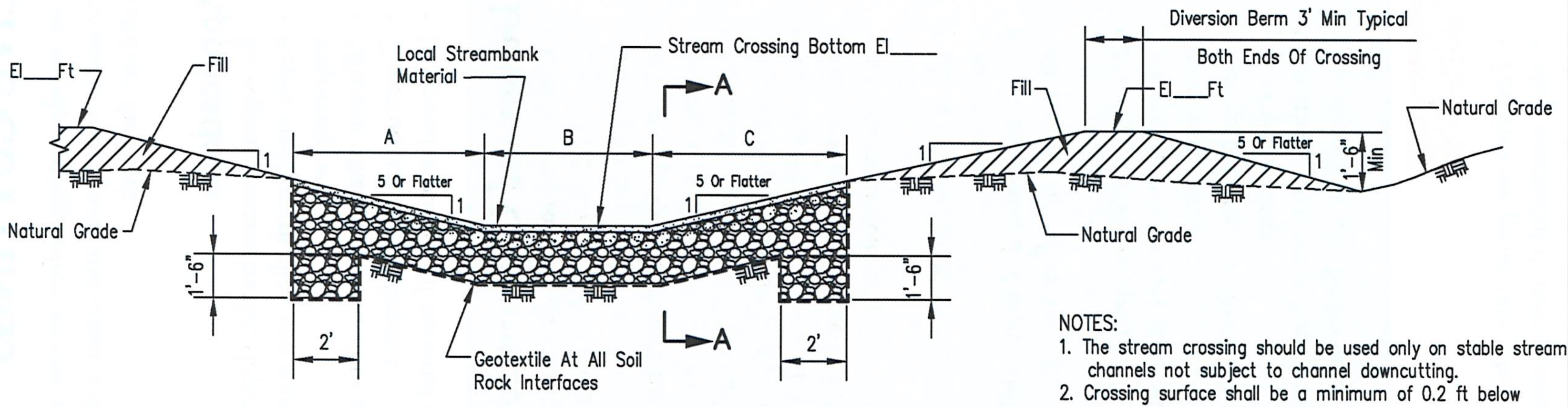
- Locate in areas where the streambed is stable
- Crossings should be no less than 6 ft and no more than 30 ft wide
- Blend approaches to the stream crossing with existing site topography
- Locate just upstream or downstream of natural barrier when possible
- Exclude livestock access to the crossing using fence and gates
- Install cross-stream fencing at fords that allows the passage of floodwater and large woody material during high flows
- Use streambank bioengineering practices to stabilize adjacent banks as necessary
- Revegetate disturbed areas after construction
- Avoid known spawning areas of sensitive species

Riparian fencing will allow woody vegetation to re-establish and a water gap provides controlled access to water for livestock. Larger riparian enclosures can compliment rotational grazing and provide additional room for streams to migrate.

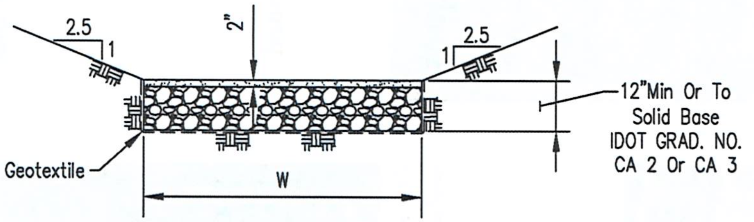
A hardened crossing provides a discrete area for livestock to access the stream and additional pastures. The swinging flood gate placed across the water with drop PVC pipes allows for high flows and debris to pass.

CAUTION

- Geotextile may not be required at well armored sites
- Biodegradable geotextile should be used if necessary
- Do not create a passage barrier where aquatic species are present and using the stream



PROFILE ALONG CENTERLINE OF CROSSING



SECTION A–A

DIMENSIONS
A = _________(Ft)
B = _________(Ft)
C = _________(Ft)
W = _________(Ft)
Station________

ESTIMATED QUANTITIES	
Excavation	Cu.Yd.
Coarse Aggregate	Tons.
Geotextile	Sq.Yd.
Seeding	Acres

Landowner		Location	

NOTES:

1. The stream crossing should be used only on stable stream channels not subject to channel downcutting.
2. Crossing surface shall be a minimum of 0.2 ft below channel invert.
3. Surfacing material shall be compacted so that the entire surface is traversed by not less than one tread track of the load hauling equipment.
4. Berms at each end of the crossing shall be constructed to direct surface flow away from excavated crossing, as directed by the engineer.
5. All disturbed areas not covered by gravel shall be seeded in accordance with Crtical Area Planting Standard (Practice Code 342).
6. Excavated material shall be removed from site, used for diversion berms or placed at least 12 feet from top edge of back slope and spread so that the height does not exceed 1 foot. The spoil material shall drain freely.
7. Geotextile (non-woven) minimum criteria:
   Weight of Geotextile (oz/sq.yd.)____________6
   Tensile strength (lb) ASTM D 4632____________180
   Elongation at failure (%) ASTM D 4632____________≥ 50
   Puncture (lb) ASTM D 4833____________80
   Ultraviolet light ASTM D 4355____________70
   Apparent opening size (AOS) ASTM D 4751__max 40 sieve
   Permittivity sec^{-1} ASTM D 4491____________0.70
8. Any geotextile splices shall overlap a minimum of 18 inches, with upstream or upslope geotextile overlapping the abutting downslope geotextile.

		Date
Designed		
Drawn	M.QUINONES	5/09
Checked		
Approved		

STREAM CROSSING FOR LIVESTOCK

NRCS
Natural Resources Conservation Service
United States Department of Agriculture

File No.
IL-ENG-179
Drawing No.

Sheet 1 of 1

LIVE CUTTINGS

Live woody cuttings, often willow, are tamped into the soil to root, grow, and create a dense root mat that stabilizes the bank.

Applications

- Re-vegetate stream banks, slopes, floodplain
- Repair small earth slips and slumps that are frequently wet
- Effective where site conditions are uncomplicated
- Construction time is limited
- Inexpensive method if material is available

Live willow cuttings seem to survive best when cut and planted in the early spring prior to bud break.

Design and Construction Techniques

- Can be used to stake down geotextile erosion control fabric or stabilize areas between other soil bioengineering techniques
- Where appropriate, should be used with other soil bioengineering and vegetative plantings
- Enhances conditions for establishment of vegetation from the surrounding plant community
- Stakes are 2 to 4 feet long, 0.5 to 1.5 inch in diameter, and are inserted with basel end to water table or saturated soil (~75% of stems covered in soil)
- Using rebar or dibble speeds installation with a starter hole
- Most successful if planted while dormant - in fall after leaves fall off to spring prior to leaves budding
- Most native willow species are suitable; using more than one species of locally sourced willows is most successful
- Beaver, rodents, and livestock can reduce survival of new plantings
- Locations within the floodplain, or where erosive forces are low, can be sprigged with cuttings alone

Willow cuttings work well planted through geotextile fabric if the basal end of the cutting can reach the water table. Irrigation is also useful to help establish new cuttings.

CAUTION

- Requires toe protection where excessive toe scour is anticipated
- Most successful if used in conjunction with geotextile (organic fabric) or rock treatments within the high water mark
- Must be in contact with the groundwater for substantial portions of the year to establish cuttings
- May require protection from animals during establishment

DORMANT POLE PLANTINGS

Plantings of cottonwood, willow, dogwood, or other species are driven into streambanks to increase channel roughness, reduce flow velocities near the slope face, increase shade, and trap sediment.

Dormant willow poles have the best survival when they do not compete with mature sod.

Applications

- Most types of streambeds where poles can be inserted to reach water table
- Stabilize rotational failures on streambanks where minor bank sloughing is occurring
- Establishing riparian trees in arid regions where water tables are deep
- Will reduce near-bank stream velocities and cause sediment deposition in treated areas
- Joint plantings in pre-existing rip-rap
- Generally self-maintaining and will re-stem if damaged by beaver or livestock, but limiting livestock access will speed recovery
- Best suited to non-gravelly streams and where ice damage potential is low
- Poles are less likely to be removed by erosion than are live stakes or smaller cuttings
- Can be used with geotextiles and vegetative plantings to stabilize the upper bank

An excavator with a dibble is used to place plantings.

Design and Construction Techniques

- Pole plantings are often used in conjunction with rock or geotextile treatments.
- Robust species such as yellow willow or cottonwood are preferred.
- Plantings will generally require a dibble for effective installation of poles below water table.
- Use 1 inch to 5 inch diameter, dormant material collected in early spring.

CAUTION

- Unlike smaller cuttings, pole harvesting can be very destructive to the donor stand.
- Poles should be gathered as "salvage" from sites designated for clearing, or thinned from dense stands.
- Equipment access should be carefully planned to avoid damaging banks.

REVEGETATION CONSIDERATIONS

Revegetation efforts are a key component for most restoration and stabilization projects. Establishing woody shrubs and trees will promote long-term bank stability on softer bioengineering projects and can provide some ecosystem benefit to harder approaches such as rip-rap. Willow is often used because it can root and establish quickly providing bank stability even in areas where different plant composition is expected over time.

Willow Cuttings

Know Your Willows

Willows have the highest survival rate when harvested locally. Nearby plants are already adapted to local climate and soil conditions. Species such as: sandbar or coyote willow (Salix exigua), booth willow (Salix boothii), yellow willow (Salix eriocephala, S. lutea), and geyer willow (Salix geyeriana) have the highest survival rates. Drummond and Booth willow can be used successfully. Bebb's can be more difficult to establish.

Harvest Dormant Plants

Dormant willows divert energy from leaf production to root production. Establishment of plants requires growing roots, not leaves. For this reason, they are more likely to successfully root from a cutting without leaves. The dormant season extends from leaf drop in the late fall/ early winter to bud break in the early spring.

Size Matters

The optimal size of cuttings depends on the application. No matter where you plant cuttings, you want your willows to have their "toes" in the water and their "heads" in the clouds. In general, willow stakes should be about four to five feet tall and willow layers should be at least six feet long. Ideally, cuttings are thumb-sized or bigger (somewhere between ¾ and 1 ½ inches in diameter). Small whips are unlikely to root, except under ideal conditions.

Choose Wisely

Most projects easily incorporate thousands of live willow cuttings. Healthy plants that are two to seven years old (look for smooth, not rough, bark) are ideal. Cuttings should be straight with the side branches and top several inches removed. Trimming back the ends of the cuttings reduces excessive leaf growth and encourages initial root production. To establish cuttings in the first years, the plant's stored energy needs to be invested in developing roots, not leaves.

Locally harvested plant material is preferred, as it is best adapted for local conditions.

Clean plant material greater than 0.5 inches in diameter is preferred.

Willow stakes can be planted through fabric or into soils or sod.

REVEGETATION CONSIDERATIONS (continued)

Moisture is Key to Establishment

Ideally at least 6 inches of the willow stem cutting is in the mid-summer water table and approximately two-thirds of the cutting is planted into the ground with approximately one-third of the stem remaining above ground.

If long periods of inundation exceeding 30 days are likely, cuttings should be long enough to extend 6 to 12 inches above the expected high water level. Temporary irrigation can help establish new cuttings.

Sunlight Counts

Willows do best in sunny locations. Establishing willows in heavily shaded areas has reduced success. If weeds or aggressive plant species are present, the willow stem cutting should be long enough to extend both above the herbaceous summer growth (to receive adequate sunlight) and below the weed root mass (to minimize competition for space and nutrients). If tall grasses such as smooth brome or timothy are present, willow cuttings should extend above the leaves of the tall grass species.

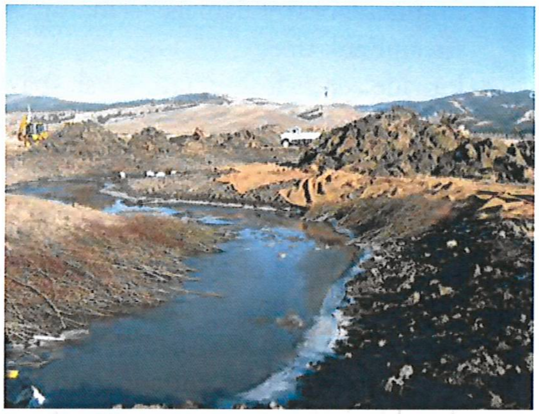
Don't Forget to Bundle and Soak

Once cuttings are harvested and pruned, bundle them into groups of 10 to 20 with twine. Ideally, cuttings should be soaked in water at least 48 hours and up to 2 weeks prior to installation. Soaking willows keeps the cuttings from drying out after being planted and encourages early root growth. Cuttings that are stored for extended periods or left in the sun have low success. Rooting hormones such as Indolebutyric acid (IBA) and napthaleneacetic acid (NAA) and others can be used in powdered or solutions to enhance rooting in difficult sites.

Browse Protection, Cuttings, Plugs and Bareroots

An alternative to rigid fencing or browse protectors is the use of repellents such as Plantskydd or Ropel (trade names for two products) that are used to discourage browse from elk, moose, deer and beaver. Plantskydd lasts up to 6 months (including over the winter). Repellents applied twice a year for a couple of years following willow installation may prove to be a better alternative to fencing.

Base of willow cuttings should touch groundwater where possible.



Soaking willows prior to planting is important to establishment. After two weeks of soaking fragile roots will emerge and may be damaged during planting.

Cuttings should be trimmed so approximately one-third of the stem is exposed.

Dormant cuttings can be stored in a cooler or snow stash 1-1.5 months before use.

MANAGING BEAVERS

Beavers helped shape the exisiting landscape and play key roles in maintaining proper channel form and function. However, beavers also have the potential for damaging property by removing trees and causing localized flooding. Landowners find that the consequences of removing beavers and their dams are often worse than learning to manage the beavers and their activities.

Beaver dams are sometimes removed to:

- Reduce flooding
- Eliminate obstructions at culverts, headgates, or bridges
- Prevent new channels from forming around dam.
- Drain wetland areas
- Eliminate beaver damage to mature streambank trees
- Provide access for migratory fish spawning areas

Culvert protection

Beaver will attempt to plug a cluvert because the sound and speed of water rushing through resembles that of a hole in their dam. There are different devices such as a "Beaver Deceiver" that block off the culvert entrance and divert the sound and feel of water moving into the culvert.

Beaver deceiver™ installed at upstream end of culvert to prevent beaver from damming.

Beaver dam removal more often results in:

- Channel downcutting
- Excess bank erosion
- Lowering water table
- Sediment realease to downstream reaches
- Streambank instability
- Damage to riparian vegetation and fisheries
- Beavers eventually rebuilding dams

Tree protection

There are several methods for protecting trees from beavers. Fencing large clumps of trees or individual trees is common. A paint mixed with sand can also prove effective by applying to the bottom 3-4 feet of the trunk.

Sand mixed with paint to match the bark of the tree can be a discrete way to prevent beaver damage. Photo courtesy of Sierra Wildlife Coalition.

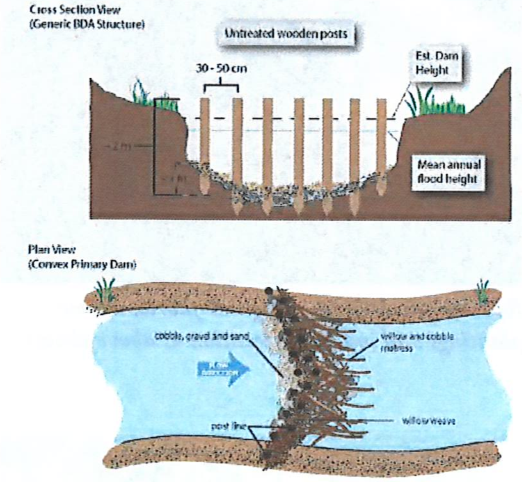
BEAVER MIMICRY

Beavers as a stream restoration tool

- Reintroduction of beavers may be a viable way to elevate the water table, aggrade incised streams, and enhance riparian vegetation where existing conditions are suitable
- Structures that mimic beaver dams, beaver dam analogs (BDA) can be used to restore incised streams; however, long-term viability requires continued maintenance or eventual re-colonization of beavers
- Beaver populations can expand rapidly in uninhabited areas with suitable habitat

BDA Design and Construction Techniques

- Install one to three rows of untreated posts or small logs spanning the width of the channel
- Space posts 12-18 inches apart and drive at least 18 inches below the channel bed
- Weave brush (e.g., green conifer) and live willow between posts, packed down tightly while still ensuring water will pass through
- Pack gravel and mud on upstream side near base
- New brush and willow should be added as old ones degrade to continue to slow flows and collect sediment
- Revegetate surrounding floodplain to enhance suitable beaver forage and habitat



Conceptual illustration of BDA using wooden posts by Elijah Portugal.

Recently installed BDAs slowing runoff and aggrading an incised channel

CAUTION

- BDAs are not appropriate in all streams or situations; structures may impede fish movement or locally degrade stream habitat by creating impoundments
- Consultation with an FWP fisheries biologist early in the planning process is recommended before installing beaver mimicry structures; they can identify potential fish passage issues and necessary permits
- Beaver dams should not be removed unless flooding upstream will cause significant damage
- Before removing beaver dams, weigh the benefit against potentially undesirable channel changes
- Legally trapping beaver requires a license or damage permit from FWP
- Given suitable habitat new beavers often relocate to the trapped area within 1-2 years
- Without adequate woody vegetation for forage and building beavers will abandon a site

SOFT BIOENGINEERING

River Stabilization or Restoration?

Set Clear Objectives

When selecting bank treatments consider the level of protection needed, and whether the project is intended to be "restoration" or "stabilization."

Restored Banks

For restoration, banks are designed to replicate natural channel stability, and allow some bank movement over time comparable to natural rates. These projects will generally employ biodegradable fabrics and rely on vegetation established for long-term protection.

Stabilized Banks

Stabilized banks are designed to withstand erosion irrespective of natural channel migration rates. These projects generally employ permanent fabrics or hard structural techniques such as rip-rap. Because hard armoring limits natural channel processes, they should be employed sparingly and carefully to avoid adverse impacts to channel stability.

Soft Bioengineering Methods

Soft bioengineering methods may be preferred where:

- Adequate vegetation can be established within several years
- Restoration has precedence over immobilizing bank
- Costs are competitive with hard engineering due to material costs (usually the case)
- Volunteers can be recruited to reduce costs
- Risk associated with natural methods is acceptable
- Hard methods are unacceptable due to potential channel impacts

Restoration of streambanks using bioengineering techniques can provide excellent bank stability and promote natural channel function.

Restored streambank using coir fabric, willow plantings and sod (same location as above photo).

Biodegradable geotextiles can last 2 to 4 years while vegetation becomes established. Note, however, that the fabric in this photo has been abraded in the first year. Ultimately, all biodegradable fabric treatments rely on vegetation for long-term stability.

FABRIC-WRAPPED BANKS

Fabric-wrapped banks are an excellent alternative to rip-rap for stabilization of eroding banks with natural vegetation.

Applications

- Restoring eroding banks with low to moderate erosive forces
- Alternative to rip-rap and other hard treatments
- In conjunction with woody debris, brush layering, or tree revetment techniques

High terrace banks are common in eastern Montana and are well suited to simple geotextile treatments.

Design and Construction Techniques

- Banks are sloped at 2:1 or less when possible; steeper 1.5:1 slopes can be vegetated, but are more vulnerable to failure
- The toe is stabilized as required (often with rock, large cobble, or woody debris)
- Geotextile fabric is wrapped over smooth slope with topsoil plus seed, or salvaged sod
- Raw fill materials may limit seed or cutting establishment. Top soil is important
- Staples, wood stakes, rebar, and willow cuttings are used to help hold fabric in place
- Cuttings or plantings can be incorporated into fabric banks, either through fabric, or in lifts

Stream banks are sloped to a 1.5:1 or 2:1 angle and covered with biodegradeable geotextile fabric. Toe protection is frequently brush or willow layers. Same location as above photo.

CAUTION

- Biodegradable fabrics eventually break down and bank stability relies on mature vegetation for long-term stability
- Unless stabilized, the toe of the bank can scour and undermine fabric
- A mature geotextile bank can be nearly as inflexible as rip-rap, and can impair channel dynamics
- Rock toes act as rip-rap and should be used only when absolutely necessary
- Fabric may be vulnerable to damage from ice and drifting woody debris before vegetation matures

This site used rock to stabilize the toe, however, brush or woody debris would have been equally effective and preferred.

GEOTEXTILE EROSION CONTROL FABRICS

Geotextile Fabrics

Erosion control fabrics are made out of many different fibers. Some are completely biodegradable, and others include a plastic mesh matrix. Heavier weight fabrics are sometimes referred to as Turf Reinforcement Mats (TRMs).

Natural Fabrics

- Coconut blankets
- Jute mesh
- Coir fabrics (700g and 900g)
- Straw

Natural materials provide short-term erosion protection, but break down over several years (typically 2 to 4 yrs). Vegetation must provide long-term erosion resistance.

Synthetic Fabrics

Synthetic fabrics are permanent and break down slowly if exposed to sunlight (over decades). They are not recommended (and in some cases prohibited) for use below the ordinary high water mark because plastic can cause entanglement of birds, snakes, and aquatic life in the mesh.

Soft Bioengineering can be strong.

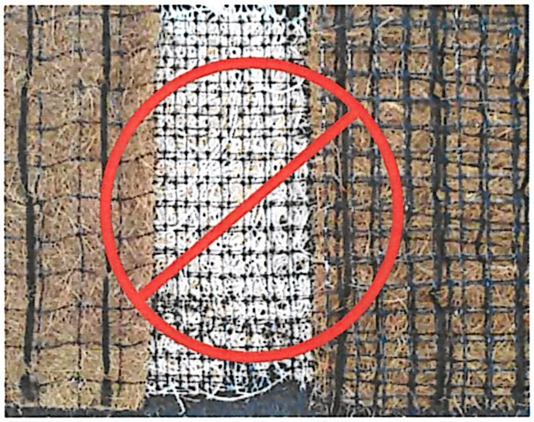
Fully revegetated fabrics can provide the equivalent protection of 2-foot rip-rap with good vegetation.

Coconut or jute blankets typically last 2 to 4 years depending on conditions, after which vegetation is most important for maintaining stability.

Fabrics are commonly used in double layers with a fine coconut fabric wrapped beneath a heavy coir mesh.

Natural fiber erosion fabrics are commonly made with coconut or jute.

Finer coconut fabrics are frequently layered beneath the coarse coir fabric to prevent loss of fine soils.



Hybrid natural and synthetic fabrics should be avoided whenever possible because the plastics can become a nuisance.

VEGETATED SOIL LIFTS

Vegetated soil lifts employ geotextile fabrics, sod, woody cuttings and plantings to achieve a naturally stabilized bank. Depending on design criteria and erosive forces of the site, vegetative soil lifts employ a range of techniques. Vegetated banks can be designed to replicate natural streambank stability and become self-sustaining as vegetation becomes established. Banks may also be designed for shorter term, temporary bank protection, or be hardened using woody debris to provide more robust protection. In particular, expected scour at the toe of the bank and countermeasures to compensate for erosive forces are primary considerations for vegetated soil lifts.

Applications

- Streambanks with light to moderate lateral erosion and good vertical stability
- Small patches of bank that have been scoured out or have slumped leaving a void (appropriate after stresses causing the slump have been removed)
- Eroded slopes or terraces where excavation is feasible to install branches/woody debris toe

Encapsulated soil lifts with LWD toe and willow cuttings.

Geotextile bank treatments can be labor-intensive. Backfilled brush layer in place, ready for first soil lift.

Design and Construction Techniques

- Brush layers may be incorporated into many types of slope and bank reconstruction
- Use live willows, cottonwood, or other plant material, preferably a species that will root
- Shape the streambank to grade less than 1.5:1. Lay plant material on the successive "lifts" of a fill or in trenches cut successively from the bottom to the top. Soil removed from each successively higher cut is used for fill over the brush below
- The cut material will vary in length depending on slope dimensions. Brush may be up to 6 feet or longer
- Cut branches should be laid in a crisscross pattern for greater stability
- Use dormant plant material cuttings (late winter, early spring or fall)
- Details on construction of soil lifts are found in the following pages

CAUTION

- Vegetated soil lifts are typically not effective in large slump areas.
- Droughty soils may limit establishment of cuttings.
- Toe protection is required where toe scour is anticipated.

BANKFULL BENCH/TERRACE

High eroding terraces are challenging to stabilize due to the steep, sometimes near vertical slope and position of the river against the toe. Construction of a bankfull bench at the toe of the slope can provide a means to stabilize the site without sloping back the high terrace. Cutting back the terrace can be difficult due to site constraints and large volumes of fill to be moved. Revegetation of steep slopes presents additional challenges.

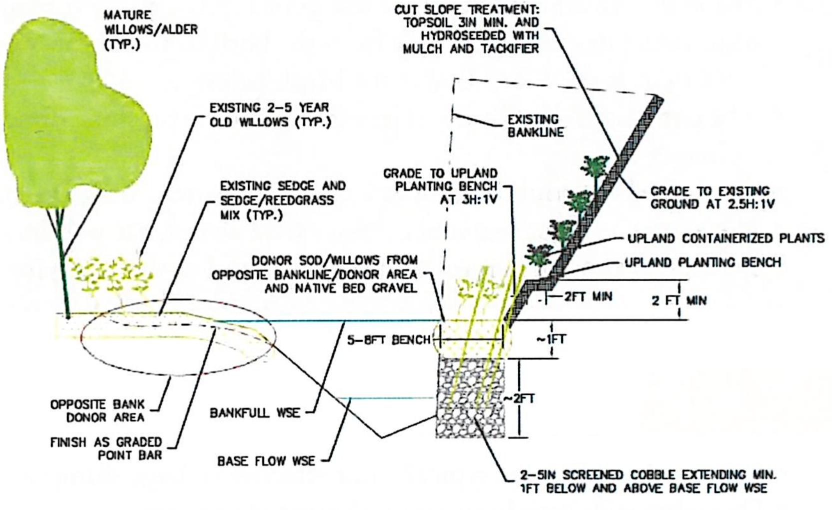
Construction of a bankfull bench normally requires encroaching on the active channel. In impaired, overwidened (high width/depth) channels, this encroachment may fall within the range of naturally functioning channel geometry. In other cases, reshaping of the channel will be required to compensate for the fill and preserve conveyance. Toe protection will also be required on outside meader or high energy systems.

In FEMA mapped floodplains, hydraulic analyses will normally be required to evaluate the potential effects the encroachment in the floodway (i.e., "no-rise" analysis). A common approach is to re-shape the channel cross section to offset the bankfull bench fill with an equivalent amount of gravel excavation on the opposite bank.

Construction materials should be appropriate to the stream's landscape setting and hydrology. The large wood and materials in the diagram may not be necessary in many streams, where cobbles, willows, and sod mats would be more contextually appropriate.

Before - An eroding bank (e.g., terrace or hillside) can sometimes be stabilized by construction of a bankfull bench. This may require channel reshaping to offset fill placed during construction of the bench.

After - Bankfull benches are most often successful where channel reshaping can take erosive pressure off the bank, or in locations without strong lateral movement and scour.



TYPICAL TREATMENT FOR 6FT+ VERTICAL BANK (NTS)

Design drawing provided by Gillilan Associates, Inc.

TOE PROTECTION

Like the foundation of a house, the toe of a bioengineered bank maintains the structural integrity of the bank during peak flows and scour. An appropriately designed toe is critical to the success of bioengineered bank treatments. Properly designed means: constructed to withstand expected scour depths, erosive force, buoyancy, and icing for the design life of the project.

Scour depths increase with the tightness of the meander, and channel substrate (bed material) varies in its inherent ability to withstand scour. Bank stabilization efforts in meandering gravel bed C channels are particularly vulnerable to undermining and failure by toe scour. In finer grained bed material and banks, slumping associated with saturated soils may also be an important factor.

The design life and deformability criteria of the treatment both factor into the type of toe construction. Not all foundations/toe treatments necessarily need or should be designed to last 100 years, or withstand a 100 yr flood. Softer treatments (e.g., using brush in lieu of large woody debris) are often warranted where maintaining a natural channel function and deformable banks is desirable.

Design Considerations:

- The toe of bioengineered banks should consider expected scour depth, deformable vs. rigid protection, design life, and channel process.
- The deepest pool in the adjacent stream reaches can be a good indicator of potential scour depth.
- From a long term ecological and channel function standpoint, woody material is generally preferred to large rock.
- Channel reshaping in conjunction with bank treatments can be an important component to achieving desired bank stability.
- Rivers with deep scour may be difficult to treat with large woody debris, as placing wood deep below the low water level creates challenges for installation (i.e., buoyancy).

In low erosion/scour locations, toe protection may be "soft" techniques such as coir logs or biodegradable fabric lifts.

In moderate scour or erosion applications, toe protection can include brush layers, fascines, and small woody debris.

A robust toe protection technique relies on large woody debris to provide a high degree of scour protection.

BRUSH FASCINES

Fascines (or wattles) are live/dormant or dead branch cuttings bound together into long, cylindrical bundles. They can be used as toe protection and in combination with reconstructed streambanks (e.g., soil lift) under moderate sheer stress conditions.

Fascines provide roughness and habitat complexity to the channel margins and short-term stability that provides time for vegetation to mature and provide long-term stream bank stability.

Fascines made from dense conifer branches or whole trees (e.g., Christmas trees) help traps sediment and provide a good medium to allow rooting of live cuttings incorporated into the fascines.

Fascines can also be used to reinforce gentle slopes above the high-water mark by trapping sediment and retaining moisture for revegetation.

Conifer fascine provides added hydrualic roughness and habitat complexity compared to coir logs or rip-rap

A conifer fascine toe with three soil lifts provide contextually appropriate treatment to stabilize this bank on the Madison River.

Design and Construction Techniques

- Prepare fascines using conifer slash, Christmas trees, or live shrubby material (e.g., willow)
- Tightly bind material together into a cylinder using heavy, biodegradable twine
- Ensure individual limbs overlap by at least 1.5 feet and stacked in alternating directions
- Individual fascines should be at least 7 feet long and up to 20 feet
- Diameter is based on sheer stress and bank configuration but should be at least 1 foot
- Fascines are set in place, bound together, and anchored with wooden stakes at the toe of the new bank
- Dormant willows cuttings should be staked into the bank through the fascine or incorporated into a soil lift on top of the fascine

CAUTION

- Vulnerable to erosion under high sheer stress
- A good anchoring system is necessary
- Not effective to control large mass movement on slopes

BRUSH AND WOOD MATRIX

A mixture of alluvium and brush or small diameter wood can provide temporary bank stability to a restored bank. The size and quantity of woody material used is dictated by the sheer stress and erosive forces on the treated bank. In high energy streams, the matrix can be constructed on a larger rock toe.

Brush is placed perpendicular to the bank, extending into the channel at different angles to provide roughness and fish habitat along the channel margins. Sod mats and other revegetation is important to provide long-term stability as the wood and brush decay. Live cuttings should also be incorporated into the matrix and staked into the top of the bank.

Similar to a brush fascine, a brush and wood matrix can also be used to stabilize the toe of a reconstructed streambank in conjunction with other bioengineered applications like a soil lift. Instead of being bundled and place horizontal to the stream, brush and wood are stacked perpedicular to the bank.

A brush matrix provides short-term stability and roughness. Native sods mats, williow cuttings, and nursey stock are planted to ensure long-term stability.

Ratio of brush and alluvium is dictated by local erosive forces.

Design and Construction Techniques

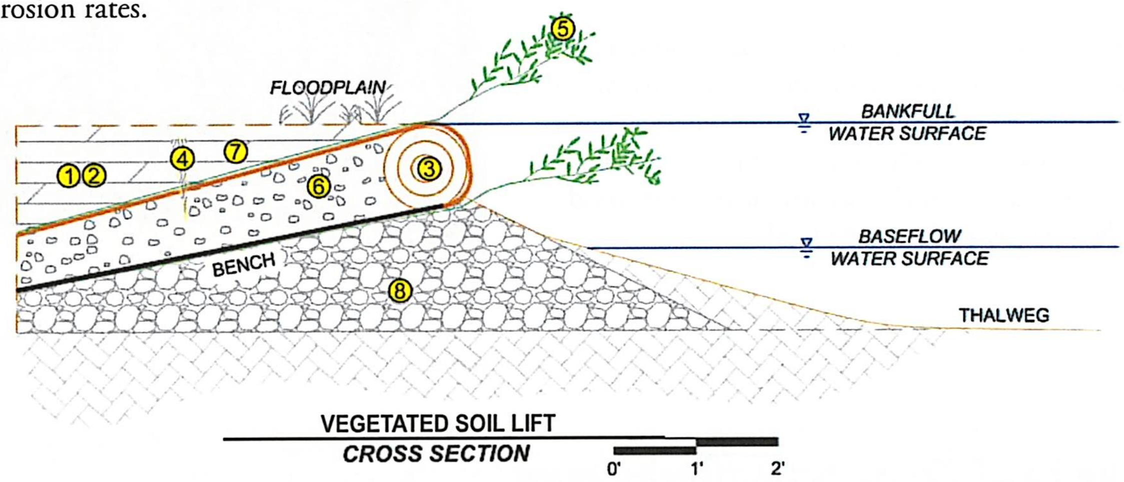
- Excavate trench at least 5 feet from edge of streambank sloping back to below streambed
- Stack and compact brush, small diameter wood, dormant willow cuttings, and mixture of native alluvium in alternating layers
- Dormant willow cuttings should be placed at the back of the trench below streambed level with at least a third of length extending above bank surface
- Bank should be constructed to approximately bankfull height

CAUTION

- Bank deformability is expected; should only be used where bank movement is tolerable
- Ensure that wood and brush are appropriately sized to the local flows and conditions
- Requires additional toe protection where excessive toe scour is anticipated
- Upstream and downstream ends of structure are most at risk of flanking and erosion

VEGETATED SOIL LIFT (Type 1) with Coir Rolls

Purpose: Revegetation, bank stabilization, channel margin roughness.
Location: Within the passive margin along riffle, run and glide features.
Stability Criteria: Built on cobble toe material, outer fabric is high strength coir, structure is anchored to bank with wooden wedge stakes.
Habitat attributes: Cover and shade
Supplemental Info: The vegetated soil lift with coir roll is a bioengineering technique that employs coir fabrics to provide conditions along the channel banks that are suitable for growing woody riparian vegetation. The method provides bank protection when used in conjunction with a sequence of other channel bed and bank structures. Typically the structure is placed along the outer bank of high-radius meander bends exhibiting poor soil conditions and a lack of vegetation. Structure performance is dependent upon vegetation growth and placement of cutting at elevations in contact with the baseflow water table during the growing seasons. The design life of the structure is temporary and intended to provide short term stability until woody vegetation becomes established. Over a period of several years, the coir products will decompose and the rooting strength of established vegetation is intended to maintain low bank erosion rates.



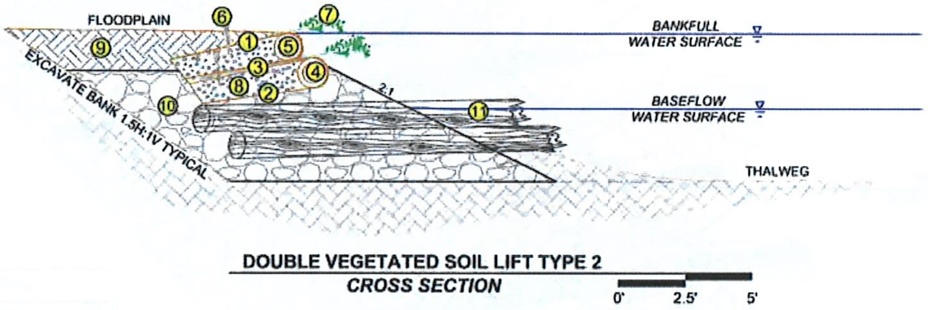
LEGEND	
① COIR MAT	⑤ WILLOW CUTTINGS
② COIR FABRIC	⑥ GRAVEL/SOIL MIX
③ COIR LOG	⑦ GROWTH MEDIA
④ WOODEN WEDGE STAKES	⑧ ALLUVIUM


Example of a constructed vegetated soil lift type 1


Example of a constructed vegetated soil lift type 1

VEGETATED SOIL LIFT (Type 2) Multiple Layers

Purpose: Revegetation, bank stabilization, channel margin roughness.
Location: Within the active margin along the outer bank of meander bends.
Stability Criteria: Built on cobble toe material with wood intermixed, outer fabric is high strength coir, structure is anchored to bank with wooden wedge stakes.
Habitat Attributes: Cover, shade, hydraulic complexity.
Supplemental info: The vegetation soil lift is a bioengineered technique that employs coir fabrics and wood to provide conditions along the channel banks that are suitable for growing woody riparian vegetation. Vegetated soil lifts provide bank protection when used in conjunction with a sequence of other channel bed and bank structures. Typically the structure is placed along the outer bank of meander bends exhibiting poor soil conditions and a lack of vegetation. Structure performance is dependent upon vegetation growth and placement of cuttings at elevations in contact with the baseflow water table during the growing season. The design life of the structure is temporary and intended to provide short term stability until woody vegetation becomes established. Over a period of several years, the coir products will decompose and the rooting strength of established vegetation is intended to maintain low bank erosion rates. Large woody debris (LWD) provides longer term toe protection.



DOUBLE VEGETATED SOIL LIFT TYPE 2
CROSS SECTION

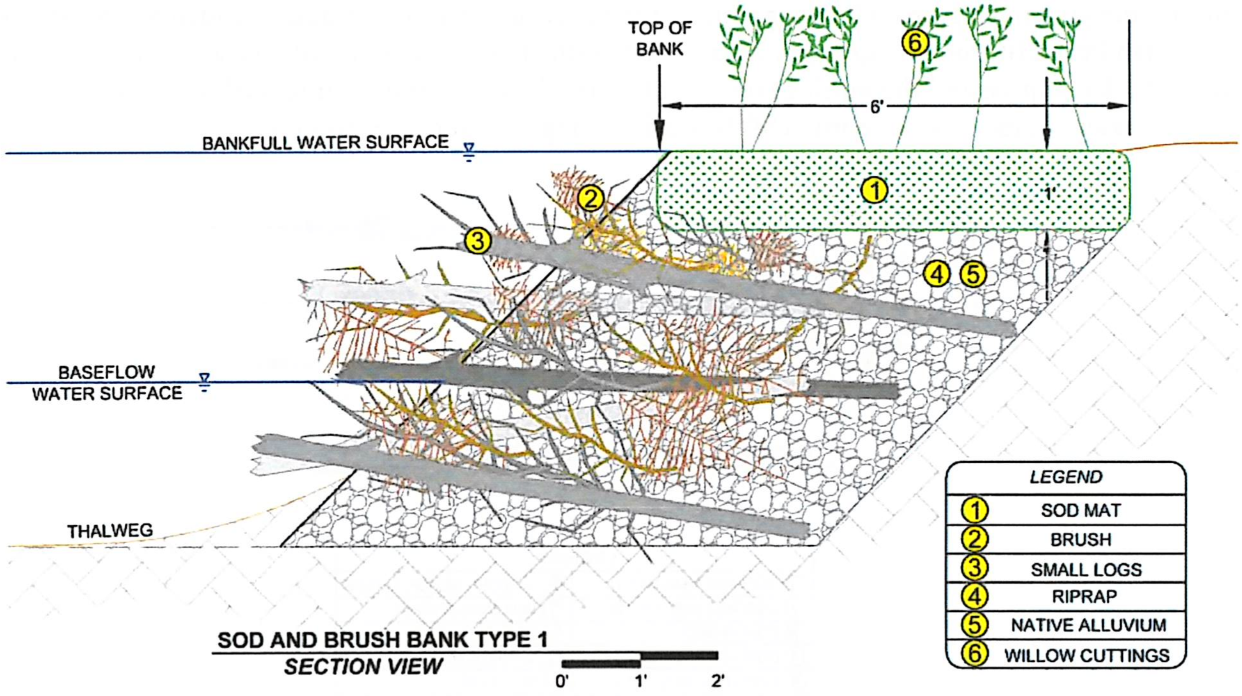
LEGEND

① COIR MAT (SOIL LIFT 1)	⑥ WOODEN WEDGE STAKES
② COIR MAT (SOIL LIFT 2)	⑦ WILLOW CUTTINGS
③ COIR FABRIC	⑧ GRAVEL/SOIL MIX
④ COIR LOG - SOIL LIFT 1	⑨ GROWTH MEDIA
⑤ COIR LOG - SOIL LIFT 2	⑩ ALLUVIUM
	⑪ TOE LOG (NO ROOTWAD)

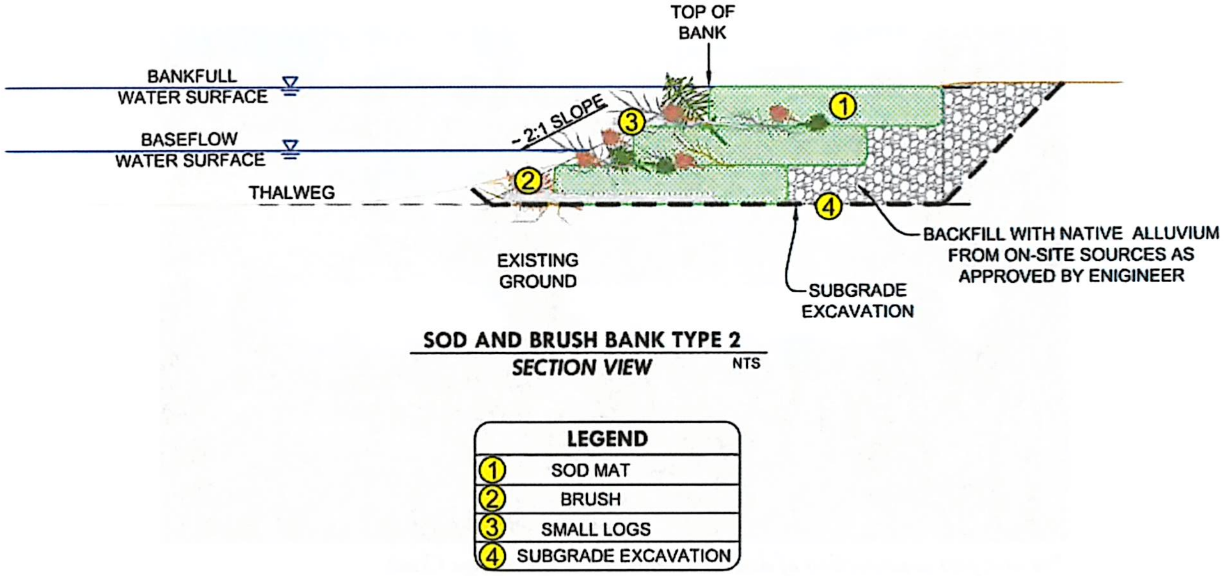
Pre and post construction of double vegetated soil lift on Rye Creek

SOD AND BRUSH MATRIX (Types 1 and 2)

Purpose: Revegetation, bank stabilization, channel margin roughness.
Location: Within the passive margin along riffle, run, and glide features.
Stability Criteria: Built on cobble, stem and brush toe material, sod mats with willow shoots create a stabile bankline.
Habitat Attributes: Cover, shade, hydraulic complexity.
Supplemental Info: The intent of this treatment is to provide temporary bank protection along newly constructed streambanks. This treatment includes placement of wetland sod mats (Type 1) or alternating layers of sod mats (Type 2) and small diameter brush intermixed with willow cuttings to provide streambank toe protection and habitat. Willow cuttings are intended to provide shade, rooting strength, and cover along the channel margins. Typical structure placement is along straight, lower stress margins of the new channel.



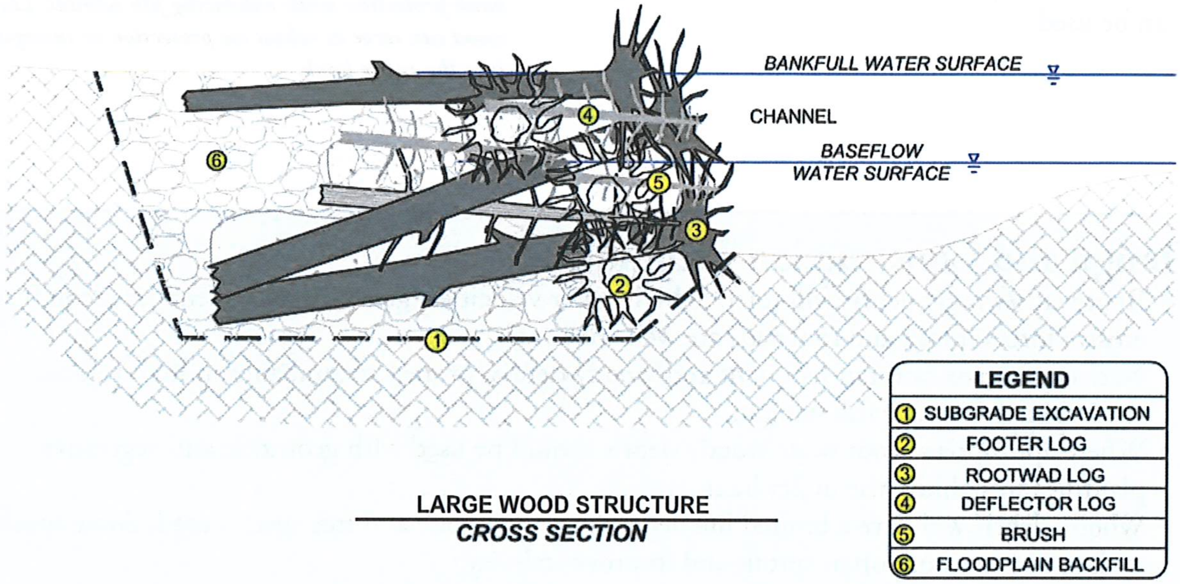
SOD AND BRUSH BANK TYPE 1
SECTION VIEW



SOD AND BRUSH BANK TYPE 2
SECTION VIEW

LARGE WOOD STRUCTURE

Purpose: Bank stabilization, channel margin roughness, flow redirection.
Location: Along the active margin of the outside meander bend, adjacent to pool features.
Stability Criteria: Built with large rootwads and boulders, structure is anchored to bank with large wood stems and stacked wood.
Habitat Attributes: Deep pool, cover, shade, low velocity, hydraulic complexity.
Supplemental Info: The large wood structure provides bank protection by re-directing flow away from the bank, dissipating energy, and maintaining a lateral scour pool. Typically structures are placed along the outer bank of a low-radius meander bend. Structure performance is dependent upon placement within a sequence of other channel bank and bed structures. Structure design life is temporary and intended to provide short-term stability until the project site is revegetated and recovers from disturbance. Over time the structure will decompose or become abandoned/buried in the floodplain as natural processes take over and the channel migrates across the floodplain.



LARGE WOOD STRUCTURE
CROSS SECTION


Example of a constructed large wood structure type 1


Example of a constructed large wood structure type 1

ROOT WADS / WOODY DEBRIS

Woody debris can be an effective bank stabilization treatment in many eroding bank settings. Several approaches are possible including continuous "root-rap," individual root structures with geotextiles, and/or mature willow transplants.

Root wad protection may be appropriate when:

- Materials can be readily obtained without damage to riparian vegetation
- Bank materials are cobble/gravel and not erodible sandy textures
- Fish habitat restoration is a priority
- Careful and experienced construction techniques can be used

Root wads and woody debris can provide substantial bank protection while enhancing fish habitat. Large wood can serve as robust toe protection or incorporated into the entire bank.

Design and Construction Techniques

- Root wads/woody debris will tolerate high water velocities (greater than 10 feet per second) and erosive forces if logs and rootwads are well anchored.
- Native materials can trap sediment and woody debris, protect streambanks in high velocity streams, and improve fish habitat.
- Where appropriate, root wads/woody debris should be used with geotextile and vegetative plantings to stabilize the upper bank.
- Woody debris will have a limited life depending on climate and tree species used. Some species, such as cottonwood, often sprout and improve stability.
- The site must be accessible to heavy equipment.
- High banks (greater than 6 to 8 feet) may limit successful placement and anchoring of boles (tree trunks).
- Use root wads with 12 to 15 feet of bole. Anchor with a footer log and rocks one-and-one-half the diameter of the boles. Bole diameters should be greater than 18 inches. Larger and higher energy rivers require larger wood.

CAUTION

- Can create excessive scour and erosion with potential loss of structure if not adequately anchored
- Might need eventual replacement if revegetation is poor or soil bioengineering is not used along with the structure
- Can be expensive and time consuming to install, especially on high steep banks
- Excavation for boles can destabilize banks and damage root systems of existing trees

ENGINEERED LOG JAM

Engineered Log Jams (ELJs) are in-stream structures designed to emulate natural accumulations of large woody debris. ELJs can be designed to alter flow patterns, protect river banks, and create habitat.

Bank Protection ELJs are constructed at intervals along a river to re-direct high velocities from the near-bank. As the channel adjusts to the ELJ structures, the river bank can be left to revegetate naturally, or be restored using other bioengineering methods such as vegetated soil lifts. The spacing, size and orientation of ELJs depends on the specifics of the site, including channel dimensions, bank height, meander curvature, scour depths and other factors.

Application of ELJs provides the advantage of natural, biodegradable materials, helps create hydraulic diversity and habitat, and may integrate well into natural channel process. ELJs are best suited to sites where wood is characteristic of the stream, natural channel process is a priority, and active channel adjustments or bank movement are acceptable. ELJs are susceptible to failure by flanking or scouring, and like other methods, are particularly vulnerable on tight radius meander bends.

Construction of ELJs requires a combination of smaller and large wood pieces and some form of anchoring or ballasting. Once key piece(s) are established, smaller racking and loose members are incorporated to form a larger jam. The anchoring/ballasting can include buried stems, piles, rock, and gravel fill. In cases where public safety and property damage is a concern, an additional amount of cabling and/or ballast material may be required. Stability of ELJs requires evaluation of buoyancy, sliding, scour, or rotation, with the application of safety factors.

Constructed log jams create hydraulic diversity and can provide bank protection.

Mature log jams can collect debris over time and provide a natural element for bank protection.

CAUTION

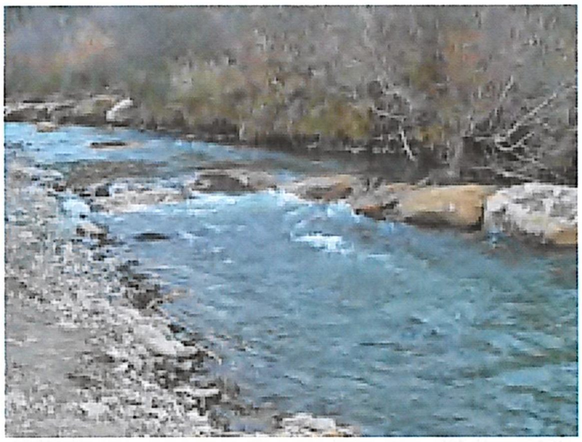
- Avoid placing ELJs where failure of the structure could block a bridge or culvert.
- ELJs may present hazards for floaters and other recreational uses, especially on tight meander bends.
- ELJs cause active re-distribution of flow patterns, and localized scour/fill of streambeds. These can result in unintended consequences for stream stability.

BARBS / VANES

A barb is a low profile, sloping stone sill angled upstream that can include a "j" hook at the end. Barbs help reduce bank erosion by re-directing currents away from the bank, and are commonly spaced along the bank similar to bendway weirs.

Use barbs/vanes to:

- Reduce bank protection needs (rip-rap size and quantity) and promote natural banks
- Protect banks for gentle (wide radius) meanders, or relatively straight banks
- Help deflect ice and woody debris from vegetative bank treatments while they become established



Barbs are constructed with a low sloping profile and gently "roll" the current away from the bank.

Design and Construction Techniques

- Design parameters, particularly for shape and orientation, are somewhat subjective.
- Design and installation requires a substantial amount of professional judgment.
- Spacing is variable with meander curve (75 to 150 feet is typical on major rivers).
- Key requirements included keying into the bank (15 feet typical) and bed (4 to 6 feet typical).
- Slope of barb generally replicates natural point bars.
- Length is variable with channel (up to one-quarter base flow width in some cases).
- Barb angle is variable with radius of meander curve and current approach angle (20 to 30 degrees from bank is common, but can vary according to design criteria).
- Rock size is according to shear stress and scour (2 to 4 feet rocks are typical).
- Barb elevation is variable, from matching natural gravel bars, to several feet above streambed.
- Downstream "boil" or turbulence, or upstream eddy, indicates problems with installation.

CAUTION

- Barbs are generally not appropriate for smaller rivers (less than 50 feet bankfull width).
- Erosion ("scalloping") will occur if incorrectly designed (too high, wrong angle in river, poor site).
- Barbs are not appropriate for tight radius meanders.
- Barbs often perform poorly in strongly aggrading or degrading channels.
- Design barbs for optimum performance at high flow.
- Incorrect design can cause scouring, destructive eddies along bank, and channel shifts.
- Experienced design and installation is important to success. Failure can have drastic effects to the stream.
- Expect continued maintenance to maintain intended functions.

BENDWAY WEIRS

A bendway weir is a low-profile upstream-angled stone sill keyed into the outer bank of a bed. Bendways are used to deflect flows away from the bank and can provide an alternative to rip-rap for bank protection. Bendway weirs reduce erosion by reducing flow velocities on the outer bank of the bend, and by re-directing current alignment through the bend and downstream crossing.

A bendway weir has a gradually sloping profile which shifts the main channel of the river to the outside of the structure. Peak flows continue to use the channel cross section above the weir elevation.

Applications

- Use on long reaches of relatively straight or gently curving banks that need protection
- Use to reduce bank protection needs and promote natural banks
- Bendways should be designed by an engineer and constructed by an experienced contractor

Design and Construction Techniques

- Bendway design varies according to engineering specifications.
- Bendways are keyed into the bank (15 feet is typical).
- Spacing is variable with meander curve and tangent of current streamline (150 feet is typical on big rivers).
- Slope should replicate natural point bars, and sometimes steeper.
- Length is variable with channel width, usually less than 20 percent of channel width.
- Weir angle is variable with meander curve (30 to 45 degree angle upstream typical).
- Rock size should be according to shear stress/scour (2- to 3-foot rocks are typical).
- Weir elevation is variable, from matching natural gravel bars, to several feet above bed.
- Permitting agencies will likely receive flood modeling and an evaluation of channel capacity, sediment transport, and downstream effects.

CAUTION

- Bendway weirs are generally not appropriate for rivers smaller than 100 feet bankfull width.
- Scalloping (bank erosion) will occur between weirs if incorrectly designed (too high or at wrong angle in the river).
- Bendways are not appropriate for tightly meandering channels.
- Design bendways with high flow performance in mind.
- Incorrect design can cause the channel to cut a new path on the opposite bank.
- Hire consultants experienced in design and installation.
- Expect continued maintenance to maintain intended functions.

ROCK V AND W WEIRS / CROSS VANES

Rock V and W weirs are used for grade control and adjustment of width-to-depth ratio in existing or reconstructed stream channels. Upstream pointing Vs or Ws are preferred for bank protection because they provide mid-channel scour pools below the weir, which may be used as holding and feeding areas for fish.

This crossvane weir is designed to control width-to-depth ratio alignment at a bridge cross section. Caution: sediment transport can be reduced causing channel instability in high bedload rivers.

Applications

- Use to control channel bed elevation and width-to-depth ratio
- Reduces grade and directs flows to center of channel which promotes bank stability
- Can be used for irrigation diversion
- Permanent bed elevation will not adversely affect channel stability
- Provides wide shallow channels
- Use "V" shape for narrow channels; "W" shape for larger channels
- Adequately sized rock is usually available

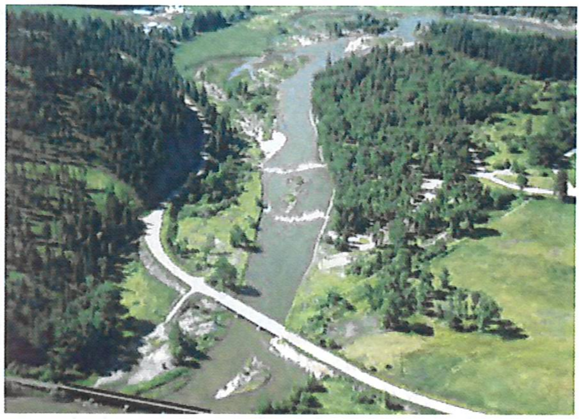
Design and Construction Techniques

- Rule of thumb is to maintain 1.5 foot or less of drop over each structure.
- Large angular boulders are most desirable to prevent movement during high flows.
- Footer rocks keyed into the bank are required to prevent scour and undermining.
- An increased weir length will cause less fluctuation in water height with change in discharge.
- Pools rapidly fill with sediment in streams carrying heavy bed material loads.
- Boulder weirs are generally more permeable than other materials and might not perform well for diverting flows in irrigation applications.
- Designs should match natural width-to-depth ratio and avoid restricting channel cross sections.
- Downstream orientation can serve specific functions, but use caution to prevent failures.
- With center at lower elevation than the sides, weirs will maintain a concentrated low flow channel.

CAUTION

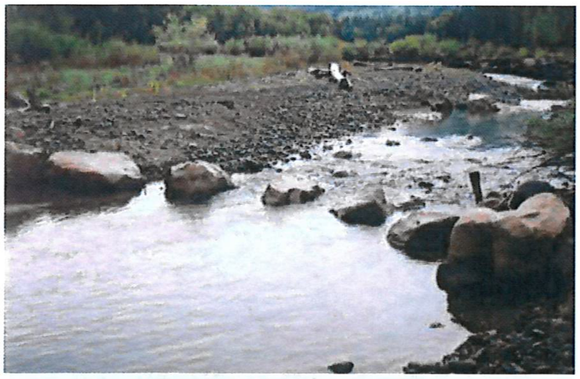
- Improper design (often excessively high elevation, construction of channel, or poor alignment) of structure can cause scouring ("whirlpool effect") and destabilize channel.
- Weirs placed in sand bed streams are inappropriate and subject to failure by undermining.
- Weirs placed in strongly aggrading systems may become ineffective as sediments fill around structure.
- Weirs have the potential to become low-flow fish migration barriers.
- Avoid constricting high bedload channels.
- An experienced hydrologist or river engineer should assist with design of larger structures, or in unstable stream environments.
- Expect continued maintenance to maintain intended functions.

ROCK V AND W WEIRS / CROSS VANES (continued)

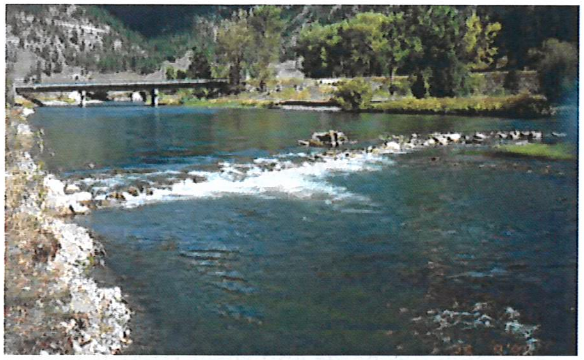


These large weirs eventually failed because they were built too high, and restricted sediment passage. Removal of these structures came at a high cost.

Large weirs must frequently be built in series to avoid large drops exceeding structural stability. Construction of weirs in high bedload transport streams always carries some risk of failure.



True "V" weirs generally have a row of cap rocks with spaces, rather than a flat sill. This promotes bedload passage (to some extent), but does not always work well for irrigation diversion needs.



One of the structures at left, prior to failure. The warning signs were apparent, notably the elevation of apex above the bed, and 2-ft + high drop over the flat sill.

Large weirs on unstable rivers can run to over $100,000 and still carry substantial risk of failure. Bedload deposition and scour can result in channel changes that bury weirs and scour away footings. Rivers may quickly cut new channels around the structure.

Rock vanes can be incorporated into natural channel design to provide grade control and reference habitat conditions.

RIP-RAP

Rip-rap and other hard armoring methods should be considered the last resort for stabilizing banks. Impacts on channel stability and fisheries can be substantial. Consider other options, such as root wads, geotextiles, barbs, vanes, and bendways. Where high strength is needed, use turf reinforcement mats with a rock toe.

Use rip-rap only when:

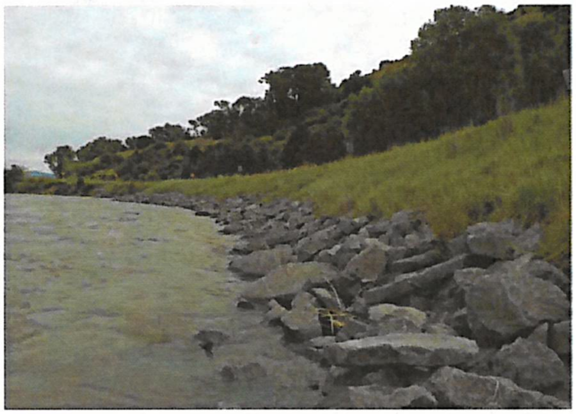
- Rigid long-term durability is needed
- Design discharge and shear stress is high
- There is substantial threat to high-value property
- Impacts to channel stability and fisheries would be minimal
- There is no practical way to incorporate vegetation or wood into the design
- Effective alternative practices are unavailable

Design and Construction Techniques

- If you must install rip-rap, use it with bioengineering and vegetative plantings to stabilize the upper bank. Techniques described on pages 3.10-3.11.
- Rip-rap areas should be vegetated to increase aesthetics and stream function. Hoag link
- The toe is the most important part of a rip-rap project. This is the zone of highest erosion.
- The key must be placed below scour depth.
- Rock is unnecessary above high water mark.
- 2:1 is the recommended slope. 1.5:1 is the steepest slop on which rip-rap will stabilize.
- Rock must be angular, not rounded, for greatest strength.
- Rock is sized according to shear stress criteria for engineered designs.
- Filter layer of gravel is needed where sandy textures will result in loss of fines through rock. Geotextile can be used but prevents root penetration where woody vegetation is desired.
- Rip-rap is flexible and not impaired by slight movement from settlement.

A well designed rip-rap job has 2:1 slopes and does not encroach on the river. This bank may have been stabilized using geotextile and vegetative methods with equal success. Note that Erosion has moved downstream below this rip-rapped bank.

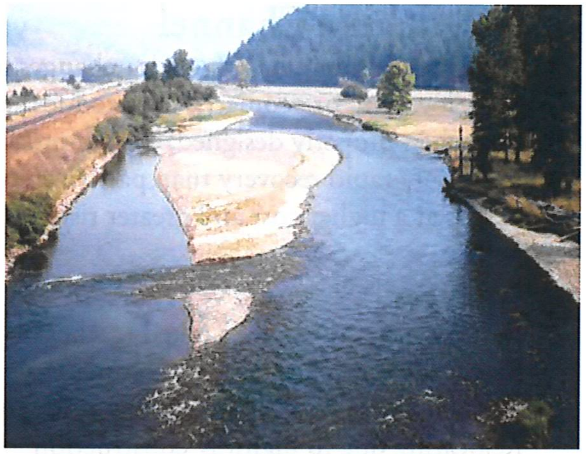
An engineered rip-rap bank provides a high degree of protection, but diminishes natural river and aesthetic values. These can be enhanced by incorporating vegetation above high water mark.



The upper bank stabilized with natural geotextile fabbric has been successfully revegetated for aesthetic value. Incorporating willows within the rip-rap can further enhance natural processes.

RIP-RAP (continued)

Receding bank upstream of a rip-rap job will eventually lead to failure.



Rip-rap on channelized reaches will limit the ability of the stream to re-establish equilibrium.

Concrete is generally not acceptable for large angular rock rip-rap. Contact Montana DEQ for guidance regarding use of concrete as rip-rap.

Willow can be successfully incorporated into rip-rap providing added water quality and habitat benefit.

Consider using vegetative techniques to stabilize banks whenever possible.

CAUTION

- Do not use rip-rap where vegetative or soil bioengineering methods are viable.
- Rip-rap should not extend above the bankfull elevation.
- Rip-rap can be expensive if materials are not locally available.
- Install fabric or gravel bedding to prevent piping of fines.
- The design slope should not be steeper than 1.5:1.
- The bank should be sloped back to minimize rip-rap encroachment on the river.
- Keyed rock toe and key at ends of project are essential to long term performance.
- Rip-rap may increase velocities and depth along treated bank, with substantial impacts up and downstream.
- Synthetic geotextile under rip-rap prohibits root penetration. Use a 6-8 inch layer of gravel instead.

CHANNEL RESTORATION APPROACHES

Modifying the Channel

Channel restoration involving major changes to channel gradient, location, or geometry can produce substantial benefits when properly designed. This approach can result in more rapid recovery than passive approaches but comes at a higher cost and greater risk.

Applications

- Restoring channelized or diked reaches
- Removing dams and other structures
- Relocating away from hazards and infrastructure
- Relocating due to highway construction
- Restoring channels impacted by extreme events (debris flows, mass failure, etc.)
- Restoring channels impacted by historical or modern land use (mining, logging, grazing, subdivisions)
- Creation of spawning channels or fish passage

Design Considerations

- Design of larger projects generally requires input from specialists including hydrologists, geomorphologists, wetland-soil scientists, biologists, and engineers.
- Permitting through the 404 program may allow channel restoration projects to be authorized under Nationwide Permit 27. This can help minimize wetland or stream channel mitigation requirements.
- Funding may be available to help with channel restoration projects which enhance natural stream function.

Re-establishing meanders in a channelized reach requires substantial hydrology and engineering design expertise.

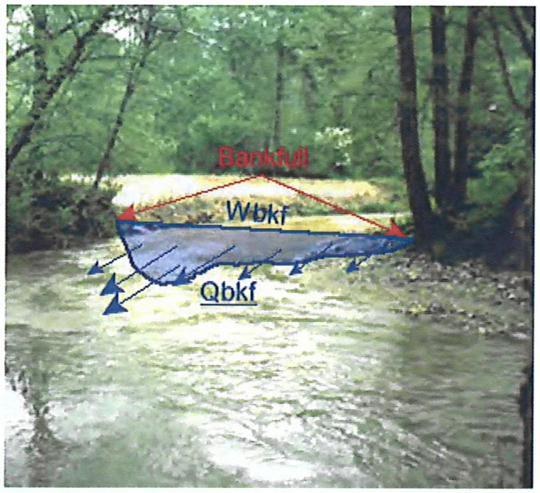
Restoring natural channel width-to-depth ratio and alignment can improve stream function. This channel was over-wide from long-term grazing impacts and restored to a narrower, deeper channel cross-section.

This meander has been restored to a more narrow, deeper form by channel shaping and bank sloping/sod mats.

CAUTION

- Major modifications to channel gradient, shape, or location can be destructive if not properly engineered.
- Channel straightening is not generally acceptable.
- Relocating channels may involve delineating wetlands, floodplains, and environmental impacts that require professional assistance.
- There is a higher risk of failure than more passive approaches.

GEOMORPHIC DESIGN PRINCIPLES



The objective of geomorphic design is to restore the dimension, pattern, and profile of a disturbed river system by emulating the natural, stable river. An example design approach that employs geomorphic principles is the Rosgen classification and associated Natural Channel Design restoration techniques (Appendix 1). Measured morphological relations associated with bankfull flow (Qbkf), bankfull width (Wbkf), geomorphic valley type, and geomorphic stream type form the basis of interpreting channel function and developing designs.

The methodology generally includes the following:

- Define specific restoration objectives associated with geomorphic process.
- Develop regional and localized information on geomorphology, hydrology, and hydraulics.
- Conduct a watershed/river assessment to determine river potential, current state, and the nature, magnitude, and probable evolution.
- Consider passive restoration recommendations based on land use change in lieu of mechanical restoration.
- Initiate natural channel design and analysis of hydraulic and sediment transport relations.
- Select and design stabilization/enhancement/vegetative treatments and materials to maintain dimension, pattern, and profile to meet restoration objectives.
- Implement the proposed design.
- Develop a monitoring plan to help evaluate effectiveness

Channel Morphology and Classification

Understanding channel form and function is key to interpreting watershed process, reach scale function, and site-specific adjustments in channel plan form, profile, and cross section.

- The Rosgen stream classification system (**Appendix 1**) defines channels according to channel metrix such as entrenchment, width-to-depth ratio, sinuosity, slope, and dominant bed material.
- These factors define eight main channel types associated with different geologic setting and valley types.
- A common channel type in Montana is a C4 channel, which is a meandering, alluvial gravel bed river with an active floodplain.
- Many stream projects are located in C4 channels, and understanding factors influencing the function of these channels is important to appropriate project design.

RESTORING CHANNEL GEOMETRY

Channel instability and bank erosion in sensitive alluvial channels is frequently related to loss of woody riparian vegetation and land use. In Rosgen C type channels, lateral bank erosion and a shift to wide, shallow channels is common. Channel instability can have adverse consequences for infrastructure, agricultural fields, diversion structures, and fish habitat. Restoration of stable channel conditions provides numerous benefits that can be fairly straightforward to implement by trained professionals. Poorly thought out projects come with additional risk that can worsen existing conditions. Restoration should rely on examination of natural reference conditions.

Strategy

1. Promote woody vegetation. This is especially important in maintaining stable channel dimensions and floodplain function. Reducing grazing pressure through riparian fencing, seasonal rotation strategies, resting, or enclosures and off-stream watering can result in rapid recovery of riparian vegetation. In time, over-wide and unstable channels will narrow and deepen as vegetation stabilizes banks.
2. Restoring reference channel cross sections, slope, and meander pattern with earthmoving and bioengineering techniques can accelerate channel recovery. This is particularly applicable to impaired stream reaches that have experienced significant channelization, down cutting, aggradation, diking, or other adverse human modifications. Stream banks and floodplain that have been fully converted to herbaceous species with any residual tree or shrub component may also benefit from active restoration strategies.
3. If required to slow lateral bank erosion, consider bioengineered vegetative treatments such as encapsulated soil lifts for eroding meander bends in pasture areas.
4. Hard structures such as rip-rap or instream rock weirs/vanes should be avoided whenever possible. Grade control for vertical instability or other considerations may warrant use of rock weirs. These require design and installation by qualified professionals to avoid adversely impacting channel function.

Natural channel design approaches such as Rosgen, NRCS, USFS, and others provide more detailed information.

CAUTION

- Streams are dynamic and respond to changes throughout the watershed, both natural and man-made. These include channel avulsions and aggradation.
- Changes to channel geometry should only be done through thoughtful planning in consultaion with professional such as engineers, hydrologists, and geomorphologists as well as relevant permitting professionals.
- Projects may result in uninteded consequences such as avulsions, aggradation, and flanking.
- Consider the over context of the problem and whether the proposed solution is sustainable, economically vaible as compared to alternative such as no action, and/or likely to transfer the problem downstream.

AVULSIONS

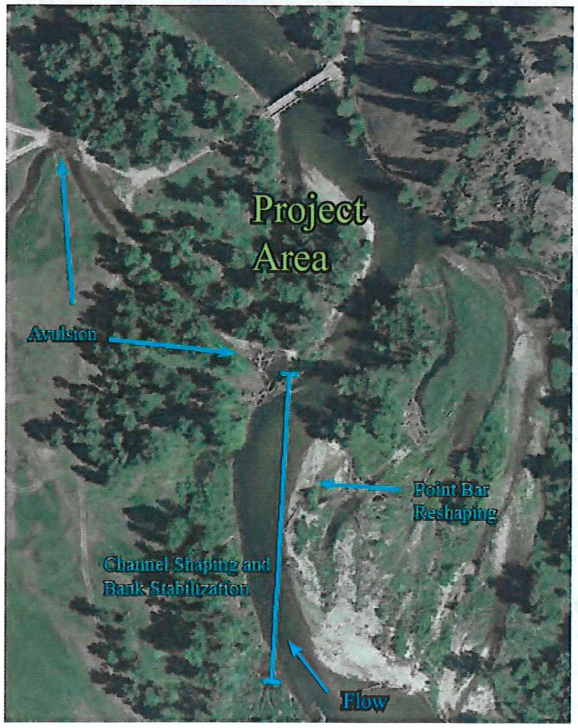
Channel cutoffs (avulsions) often result from high bedload supply and deposition in strongly meandering and high width to depth ratio alluvial channels. Avulsions are part of a dynamic stream system resulting in diverse habitats over time (chapter 2). However, impaired bank stability and poor riparian health often contribute to the tendency for avulsions.

Strategy

1. **Sediment transport.** Projects rarely are able to address sediment supply on a reach or watershed scale. Instead, project must address sediment transport by reconfiguring channel cross-section, alignment, and water conveyance capacity. The objective is to reduce depositional tendency at the avulsion
2. **Channel alignment and cross-section.** Reconfiguring the channel upstream and through the avulsion site is essential. This may require a combination of adjusting the meander curvature (reducing the meander radius), reshaping channel cross section (usually narrower, deeper) through channel spilt, reinforcing meander bank with moderate to high strength bioengineering methods.
3. Floodplain connectivity and riparian health. The entrance to avulsion often needs to be re-configured and reinforced. The entrance to the avulsion should generally be set at or near bankfull and floodplain elevation, and not be blocked or diked to prevent overbank flows. Frequent flooding in avulsion channels is best managed by reconfiguring the main channel to address sediment transport and water conveyance.

CAUTION

Controlling avulsions can result in challenging and costly undertakings. Success is not assured even for well-designed projects. Partial solutions such as blocking the avulsion without addressing channel and floodplain function is seldom successful. Cost-benefit considerations often limit these projects to protecting high value infrastructure, or as part of large scale restoration of impaired stream reaches.



1. Reshape meander alignment and configuration
2. Reshape avulsion entrance to bankfull elevation
3. Bioengineered bank stabilization of meander and avulsion entrance
4. Revegetation of floodplain and streambanks

(Left) Aerial view and proposed treatment of avulsion
(Above) Bank stabilization under construction

AGGRADATION

Aggrading channels are common in streams with high sediment supply. Gravel deposits can fill part or all of the stream cross section and cause unconfined flooding across the floodplain. Wide, shallow channels are particularly susceptible to poor sediment transport conditions. Surface flow is often lost in aggraded channels but may resurface downstream. Aggrading channels may be inherent in the landscape (e.g., alluvial fans, transitions from confined valleys to open floodplains), or may be associated with impaired riparian condition.

In many areas of Montana, the historical logging of large streamside trees decreased upstream stability and increased supplies of large sediment causing aggradation and forcing base flows subsurface.

Strategy

1. Address upstream sediment sources if possible such as eroding banks, lateral channel instability, or off-site sediment delivery.
2. Re-shape aggraded channel to an alignment and channel cross-section which will convey sediment and water within a bankfull dimension.
3. Maintain active floodplain. Move excess fill outside of floodplain and avoid creating dykes or berms.
4. Promote recovery of woody vegetation within the floodplain.
5. Bioengineered bank stabilization may be required to maintain channel cross-section and bank integrity.

An aggraded channel can completely fill with sediment and result in frequent flooding and rapid channel migration. Large sediment supplies and impaired riparian conditions are common with aggrading channel segments.

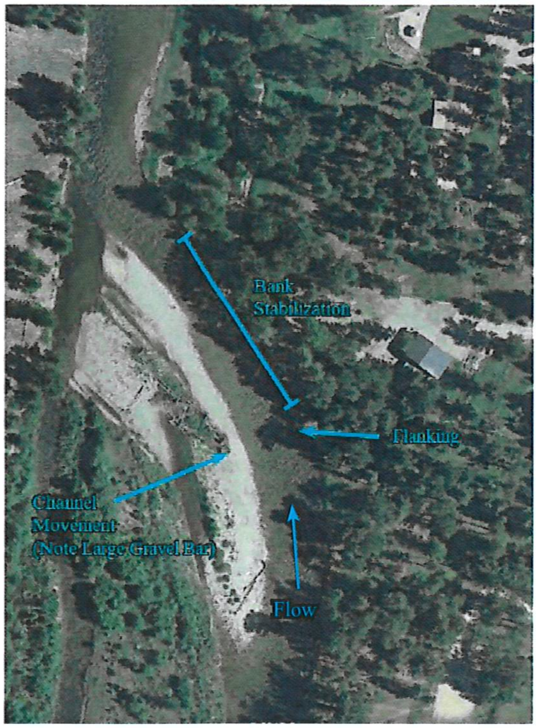
FLANKING

Flanking, or end run of a structure (e.g., rip rap) generally occurs when flow is directed toward the bank as a result of structure placement and lack of a stable anchor point. This is often addressed by increasing the size or length or of the structure. However, it points to the need to understand the broader context of the project and the appropriate remedy.

- Lateral erosion and meander movement commonly flank small projects from the upstream end.
- Bank stabilization projects often treat short sections of eroding river bank. Property ownership boundaries, financial limitations, or other considerations may limit projects to "patching" immediate problem areas, rather than addressing the larger picture of stream planform and bank erosion.
- Key trenches of rock are often designed into projects to help counteract bank recession. Eventually, river movement can bypass key trench measures.
- Recognize that projects that treat only a portion of the meander may have a limited design life and effectiveness.
- Consider the "big" picture when looking at bank stabilization, meaning the context and probability for larger scale meander migration.

Strategy

1. Revaluate meander progression. Is it moving downstream past project? Is it only moving laterally and not progressing downstream?
2. If the meander is tending to move downstream, and bank recession upstream is limited in extent, buying additional time may be worthwhile. Reconfigure upstream end of project. Construct vane or J-hook at upstream to help redirect current to center of channel. Make repairs to damaged bank as needed. Consider extending project upstream if viable option.
3. If lateral meander movement is aggressive and upstream bank recession is extensive, maintaining project may not be viable long term unless upstream meander can be treated.



(Left) The project site is located at the lower end of the meander, which is especially susceptible to flanking because the project addresses only a portion of the receding streambank.

(Above) Upstream end of project is being flanked as meander migrates to river right. Lateral meander progression suggests this 140 ft project will require additional work upstream to protect this location long-term.

STREAMBANK CONSTRUCTION SEQUENCE

Site Isolation/Dewatering

Dewatering the construction site can be a significant challenge in streambank restoration. Dewatering the site helps minimize release of sediment to downstream reaches, reduces potential impacts to aquatic life, and improves constructability. Dewatering techniques should focus first on limiting water entering and flowing through the site, and secondarily, minimizing pooled ground water. Proper placement of woody debris structures and woody debris toe reinforcement is compromised by buoyancy challenges if constructed in water. Pumping standing water can assist greatly in insuring proper installation and ballasting of woody debris. A construction dewatering permit (MPDES) is required before implementation, and dewatering may be subject to timing restrictions because of fisheries.

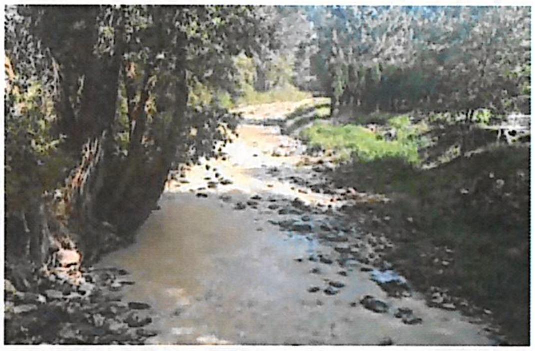
Site Preparation

Stripping sod/topsoil and salvaging woody vegetation along the streambank is an excellent source of material for restoration. Native sod is superior to topsoil or imported materials and seeding when constructing vegetated soil lifts. The latent seed source and established root systems of herbaceous and woody species offer a distinct advantage for revegetation. Rapid establishment and protection/coverage of soils beneath geotextile fabrics is key to upper bank stability.

Pumping water around a construction site is generally feasible only on smaller projects and smaller flow rates.

Ideally, in stream work can be completed "in the dry" by diverting or pumping water around the site.

Silt fence can help isolate flowing water and minimize downstream sedimentation.



Releases of sediment during instream construction can cause substantial water quality impacts.

STREAMBANK CONSTRUCTION SEQUENCE (continued)

Toe Installation

Careful construction of the bank toe is among the most important aspects of a streambank treatment. The toe of a bank is the foundation of the project and should be composed of materials appropriate to the stream conditions (3.19). The toe must be constructed to the design scour depth often requiring excavation of a trench well below the natural streambed elevation. Placement of woody debris, brush layers, or other materials to form the underlying structure of the bank is generally below or at the elevation of the streambed. A common challenge with toe construction is water in the key trench, which hampers proper placement of woody debris, ballast rock, and fill.

Placement of large woody debris forms the foundation of many stream projects on large rivers.

Fascines and brush layering can provide a foundation for less erosive environments.

Live brush layers can be used to form a toe where scour depths are not expected to undermine the treatment.

Large woody debris foundations are typically backfilled with some amount of large rock and native fill for ballast.

STREAMBANK CONSTRUCTION SEQUENCE (continued)

Brush Layers

Mixed live and dead brush layers or fascines (3.20) are often incorporated as the first layer between the toe structure and the vegetated soil lift. The brush layer provides roughness to reduce near bank velocities, and live cutting take root to reinforce the bank. Ideally, a live brush layer should have the basal end of the cuttings near the low water level, and the growing end placed at the lower limit of vegetation. The density of live stems or dead brush will vary by project. A count of 10-15 stems per linear foot, per level is common and continued irrigation increases survival. Live stems must be fresh, dormant and not allowed to desiccate in bright sunlight or during dry storage in winter. Construction in early spring, or fall is preferred to maximize cutting survival. Covering the cuttings with native fill/topsoil and watering in the cuttings with the bucket of the excavator helps solidify this layer.

A mix of live and dead brush provides bank roughness and revegetation. A high density of stems (10-15 per foot) is common.

Brush layers have the best survival when placed near the water table or in moist soils. Irrigation may be required in droughty or coarse soils.

Live cuttings should be trimmed either before or following installation.

Brush layers are placed beneath each lift of fabric.

STREAMBANK CONSTRUCTION SEQUENCE (continued)

Soil Lift

The soil lift entails layering natural geotextile fabric(s) and wrapping them over a compacted life of native backfill and a veneer of sod or topsoil beneath the fabric. Creating smooth contact between fabric and soil with sufficient staking to hold fabric tight is important, especially to prevent soil loss during high water. "Tenting" or void space under the fabric should be avoided through careful preparation of the soil surface. Any seeding must happen before the fabric is staked. The fabric segments are normally layered out constructed from the upstream to downstream directions so the fabric seams overlap like fish scales. An individual lift should not exceed one foot in thickness.

Soil lifts are commonly installed as a single or double layer ranging in thickness from 1 to 2 feet in depth.

A completed soil lift with large woody debris toe emulates the natural range of bank roughness and stability.

Soil lifts may be constructed with multiple layers. Live brush has the best chance of establishment closest to the water table.

Installation of soil lifts requires excavating the streambank 10 or more feet.