Appendixes

Appendix A

"The outstanding scientific discovery of the twentieth century is not television, or radio, but rather the complexity of the land organism. Only those who know the most about it can appreciate how little we know about it. The last word in ignorance is the man who says of an animal or plant: "What good is it?" If the land mechanism as a whole is good, then every part is good, whether we understand it nor not. If the biota, in the course of aeons, has built something we like but do not understand, then who but a fool would discard seemingly useless parts? To keep every cog and wheel is the first precaution of intelligent tinkering."

—Aldo Leopold 1953, pp. 145-146

Introduction

The user of this document is cautioned not to attempt to replicate or apply any of the techniques displayed without determining their appropriateness as an integral part of the restoration plan.

The following are presented as examples of the many techniques that are being used in support of stream corridor restoration. Only a limited number of techniques by broad category are shown as examples. Neither the number of examples nor their descriptions are intended to be exhaustive. The examples are conceptual and contain little design guidance. All restoration techniques, however, should be designed; often through an interdisciplinary approach discussed in Part II of this document. Limited guidance is provided on applications, but local standards, criteria, and specifications should always be used.

These and other techniques have specific ranges of applicability in terms of physical and climate adaptation, as well as for different physiographic regions of the country. Techniques that are selected must be components of a system designed to restore specific functions and values to the stream corridor. The use of any single technique, without consideration of system functions and values, may become a short-lived, ineffective fix laid on a system-wide problem. All restoration techniques are most effective when included as an integral part of a restoration plan. Typically a combination of techniques are prescribed to address prevailing conditions and desired goals. Effective restoration will respond to goals and objectives that are determined locally through the planning process described in Chapters 4 though 6.

The restoration plan may prescribe a variety of approaches depending on the condition of the stream corridor and the restoration goals:

- *No action*. Simply remove disturbance factors and "let nature heal itself."
- *Management*. Modify disturbance factors to allow continued use of the corridor, while the system recovers.
- *Manipulation*. Change watershed, corridor, or stream conditions through land use changes, intervention, and designed systems ranging from installing practices to altering flow conditions, to changing stream morphology and alignment.

Regardless of the techniques applied, they should restore the desired functions and achieve the goals of the restoration plan. The following are general considerations that apply to many or all of the techniques in this appendix:

- The potential adverse impacts from failure of these and other techniques should be assessed before they are used.
- Techniques that change the channel slope or cross section have a high potential for causing channel instability upstream and downstream. They should therefore be analyzed and designed by an interdisciplinary team of professionals. These techniques include: weirs, sills, grade control measures, channel realignment, and meander reconstruction.
- The potential impact on flood elevations should be analyzed before these and other techniques are used.
- Many techniques will not endure on streams subject to headcuts or general bed degradation.
- Some form of toe protection will be required for many bank treatment techniques to endure where scour of the streambank toe is anticipated.
- Any restoration technique installed in or in contact with streams, wetlands, floodplains, or other water bodies are subject to various federal, state, and local regulatory programs and requirements. Most techniques presented in this appendix would require the issuance of permits by federal, state, and local agencies prior to installation.

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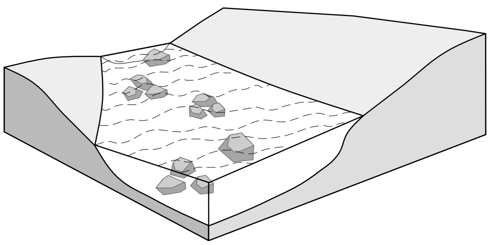
Appendix A: Techniques

INSTREAM PRACTICES

Boulder Clusters



Groups of boulders placed in the base flow channel to provide cover, create scour holes, or areas of reduced velocity.

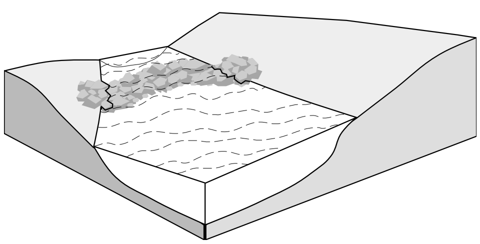
Applications and Effectiveness

- Can be used in most stream habitat types including riffles, runs, flats, glides and open pools.
- Greatest benefits are realized in streams with average flows exceeding 2 feet per second.
- Group placements are most desirable. Individual boulder placement might be effective in very small streams.
- Most effective in wide, shallow streams with gravel or rubble beds.
- Also useful in deeper streams for providing cover and improving sub-strate.
- Not recommended for sand bed (and smaller bed materials) streams because they tend to get buried.
- Added erosive forces might cause channel and bank failures.
- Not recommended for streams which are aggrading or degrading.
- May promote bar formation in streams with high bed material load.

For More Information

- Consult the following references: Nos. 11, 13, 21, 34, 39, 55, 60, 65, 69.

Weirs or Sills



Log, boulder, or quarrystone structures placed across the channel and anchored to the streambank and/or bed to create pool habitat, control bed erosion, or collect and retain gravel.

Applications and Effectiveness

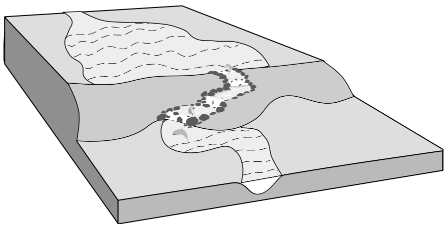
- Create structural and hydraulic diversity in uniform channels.
- If placed in series, they should not be so close together that all riffle and run habitat is eliminated.
- Pools will rapidly fill with sediment in streams transporting heavy bed material loads.
- Riffles often are created in downstream deposition areas.
- Weirs placed in sand bed streams are subject to failure by undermining.
- Potential to become low flow migration barriers.
- Selection of material is important.
  - Boulder weirs are generally more permeable than other materials and might not perform well for funneling low flows. Voids between boulders may be chinked with smaller rock and cobbles to maintain flow over the crest.
  - Large, angular boulders are most desirable to prevent movement during high flows.
  - Log weirs will eventually decompose.
- Design cross channel shape to meet specific need(s).
  - Weirs placed perpendicular to flow work well for creating backwater.
  - Diagonal orientations tend to redistribute scour and deposition patterns immediately downstream.
  - Downstream “V’s” and “U’s” can serve specific functions but caution should be exercised to prevent failures.
  - Upstream “V’s” or “U’s” provide mid-channel, scour pools below the weir for fish habitat, resting, and acceleration maneuvers during fish passage.
  - Center at lower elevation than sides will maintain a concentrated low flow channel.

For More Information

- Consult the following references: Nos. 11, 13, 44, 55, 58, 60, 69.

INSTREAM PRACTICES

Fish Passages



Any one of a number of instream changes which enhance the opportunity for target fish species to freely move to upstream areas for spawning, habitat utilization, and other life functions.

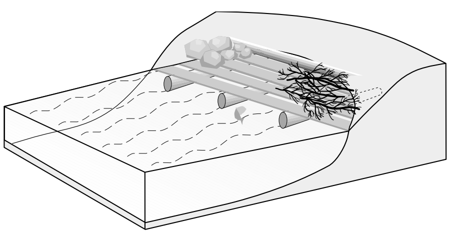
Applications and Effectiveness

- Can be appropriate in streams where natural or human placed obstructions such as waterfalls, chutes, logs, debris accumulations, beaver dams, dams, sills, and culverts interfere with fish migration.
- The aquatic ecosystem must be carefully evaluated to assure that fish passages do not adversely impact other aquatic biota and stream corridor functions.
- Slopes, depths and relative positions of the flow profile for various flow ranges are important considerations. Salmonids, for example, can easily negotiate through vertical water drops where the approach pool depth is 1.25 times the height of the (drop subject to an overall species-specific limit on height) (CA Dept. of Fish and Game, 1994).
- The consequences of obstruction removal for fish passage must be carefully evaluated. In some streams, obstructions act as barriers to undesirable exotics (e.g. sea lamprey) and are useful for scouring and sorting of materials, create important backwater habitat, enhance organic material input, serve as refuge for assorted species, help regulate water temperature, oxygenate water, and provide cultural resources.
- Designs vary from simple to complex depending on the site and the target species.

For More Information

- Consult the following references: Nos., 11, 69, 81.

Log/Brush/Rock Shelters



Logs, brush, and rock structures installed in the lower portion of streambanks to enhance fish habitat, encourage food web dynamics, prevent streambank erosion, and provide shading.

Applications and Effectiveness

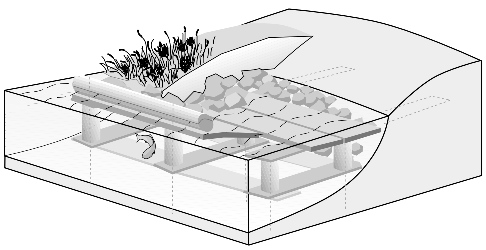
- Most effective in low gradient stream bends and meanders where open pools are already present and overhead cover is needed.
- Create an environment for insects and other organisms to provide an additional food source.
- Can be constructed from readily available materials found near the site.
- Not appropriate for unstable streams which are experiencing severe bank erosion and/or bed degradation unless integrated with other stabilization measures.
- Important in streams where aquatic habitat deficiencies exist.
- Should, where appropriate, be used with soil bioengineering systems and vegetative plantings to stabilize the upper bank and ensure a regenerative source of streambank vegetation.
- Not generally as effective on the inside of bendways.

For More Information

- Consult the following references: Nos. 11, 13, 39, 55, 65.

INSTREAM PRACTICES

Lunker Structures



Cells constructed of heavy wooden planks and blocks which are imbedded into the toe of streambanks at channel bed level to provide covered compartments for fish shelter, habitat, and prevention of streambank erosion.

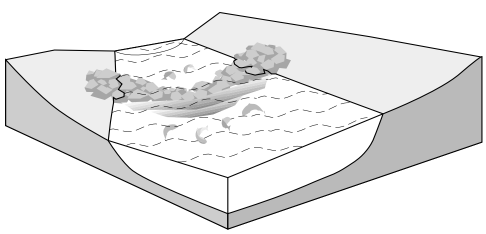
Applications and Effectiveness

- Appropriate along outside bends of streams where water depths can be maintained at or above the top of the structure.
- Suited to streams where fish habitat deficiencies exist.
- Should, where appropriate, be used with soil bioengineering systems and vegetative plantings to stabilize the upper bank and ensure a regenerative source of streambank vegetation.
- Are often used in conjunction with wing deflectors and weirs to direct and manipulate flows.
- Are not recommended for streams with heavy bed material loads.
- Most commonly used in streams with gravel-cobble beds.
- Heavy equipment may be necessary for excavating and installing the materials.
- Can be expensive.

For More Information

- Consult the following references: Nos. 10, 60, 65, 85.

Migration Barriers



Obstacles placed at strategic locations along streams to prevent undesirable species from accessing upstream areas.

Applications and Effectiveness

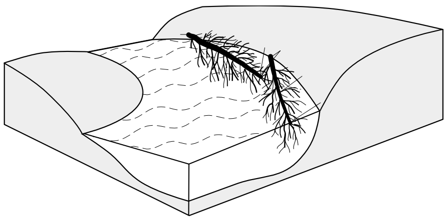
- Effective for specific fishery management needs such as separating species or controlling nuisance species by creating a barrier to migration.
- Must be carefully evaluated to assure migration barriers do not adversely impact other aquatic biota and stream corridor functions.
- Both physical structures or electronic measures can be used as barriers.
  - Structures can be installed across most streams, but in general they are most practical in streams with baseflows depths under two feet and widths under thirty feet.
  - Temporary measures such as seines can also be used under the above conditions.
  - Electronic barriers can be installed in deeper channels to discourage passage. Electronic barrier employs lights, electrical pulses or sound frequencies to discourage fish from entering the area. This technique has the advantage of not disturbing the stream and providing a solution for control in deep water.
- Barriers should be designed so that flood flows will not flank them and cause failures.

For More Information

- Consult the following references: Nos. 11, 55.

INSTREAM PRACTICES

Tree Cover



Felled trees placed along the streambank to provide overhead cover, aquatic organism substrate and habitat, stream current deflection, scouring, deposition, and drift catchment.

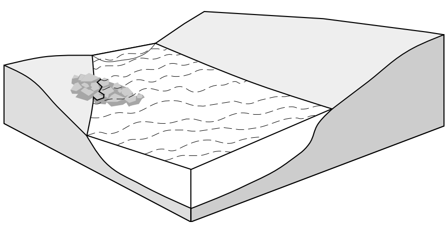
Applications and Effectiveness

- Can provide benefits at a low installation cost.
- Particularly advantageous in streams where the bed is unstable and felled trees can be secured from the top of bank.
- Channels must be large enough to accommodate trees without threatening bank erosion and limiting needed channel flow capacity.
- Design of adequate anchoring systems is necessary.
- Not recommended if debris jams on downstream bridges might cause subsequent problems.
- Require frequent maintenance.
- Susceptible to ice damage.

For More Information

- Consult the following references: Nos. 11, 55, 69.

Wing Deflectors



Structures that protrude from either streambank but do not extend entirely across a channel. They deflect flows away from the bank, and scour pools by constricting the channel and accelerating flow.

Applications and Effectiveness

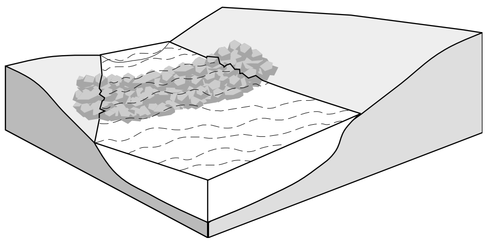
- Should be designed and located far enough downstream from riffle areas to avoid backwater effects that would drown out or otherwise damage the riffle.
- Should be sized based on anticipated scour.
- The material washed out of scour holes is usually deposited a short distance downstream to form a bar or riffle area. These areas of deposition are often composed of clean gravels that provide excellent habitat for certain species.
- Can be installed in series on alternative streambanks to produce a meandering thalweg and associated structural diversity.
- Rock and rock-filled log crib deflector structures are most common.
- Should be used in channels with low physical habitat diversity, particularly those with a lack of stable pool habitat.
- Deflectors placed in sand bed streams may settle or fail due to erosion of sand, and in these areas a filter layer or geotextile might be needed underneath the deflector.

For More Information

- Consult the following references: Nos. 10, 11, 18, 21, 34, 48, 55, 59, 65, 69, 77.

INSTREAM PRACTICES

Grade Control Measures



Rock, wood, earth, and other material structures placed across the channel and anchored in the streambanks to provide a "hard point" in the streambed that resists the erosion forces of the degradational zone, and/or to reduce the upstream energy slope to prevent bed scour.

Applications and Effectiveness

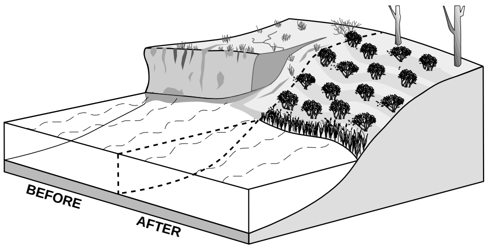
- If a stable channel bed is essential to the design, grade control should be considered as a first step before any restoration measures are implemented (if degradational processes exist in channel system).
- Used to stop headcutting in degrading channels.
- Used to build bed of incised stream to higher elevation.
- Can improve bank stability in an incised channel by reducing bank heights.
- Man-made scour holes downstream of structures can provide improved aquatic habitat.
- Upstream pool areas created by structures provide increased low water depths for aquatic habitat.
- Potential to become low flow migration barrier.
- Can be designed to allow fish passage.
- If significant filling occurs upstream of structure, then downstream channel degradation may result.
- Upstream sediment deposition may cause increased meandering tendencies.
- Siting of structures is critical component of design process, including soil mechanics and geotechnical engineering.
- Design of grade control structures should be accomplished by an experienced river engineer.

For More Information

- Consult the following references: Nos. 1, 4, 5, 6, 7, 12, 17, 18, 25, 26, 31, 37, 40, 63, 66, 84.

STREAMBANK TREATMENT

Bank Shaping and Planting



Regrading streambanks to a stable slope, placing topsoil and other materials needed for sustaining plant growth, and selecting, installing and establishing appropriate plant species.

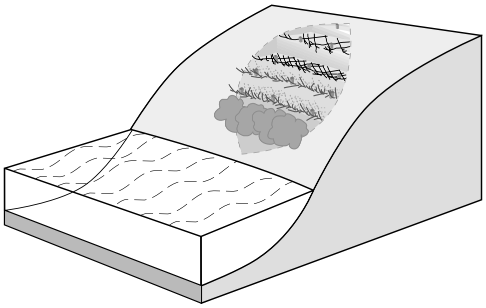
Applications and Effectiveness

- Most successful on streambanks where moderate erosion and channel migration are anticipated.
- Reinforcement at the toe of the embankment is often needed.
- Enhances conditions for colonization of native species.
- Used in conjunction with other protective practices where flow velocities exceed the tolerance range for available plants, and where erosion occurs below base flows.
- Streambank soil materials, probable groundwater fluctuation, and bank loading conditions are factors for determining appropriate slope conditions.
- Slope stability analyses are recommended.

For More Information

- Consult the following references: Nos. 11, 14, 56, 61, 65, 67, 68, 77, 79.

Branch Packing



Alternate layers of live branches and compacted backfill which stabilize and revegetate slumps and holes in streambanks.

Applications and Effectiveness

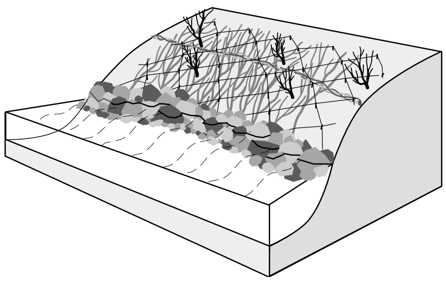
- Commonly used where patches of streambank have been scoured out or have slumped leaving a void.
- Appropriate after stresses causing the slump have been removed.
- Less commonly used on eroded slopes where excavation is required to install the branches.
- Produces a filter barrier that prevents erosion and scouring from streambank or overbank flows.
- Rapidly establishes a vegetated streambank.
- Enhances conditions for colonization of native species.
- Provides immediate soil reinforcement.
- Live branches serve as tensile inclusions for reinforcement once installed.
- Typically not effective in slump areas greater than four feet deep or four feet wide.

For More Information

- Consult the following references: Nos. 14, 21, 34, 79, 81.

STREAMBANK TREATMENT

Brush Mattresses



Combination of live stakes, live facines, and branch cuttings installed to cover and physically protect streambanks; eventually to sprout and establish numerous individual plants.

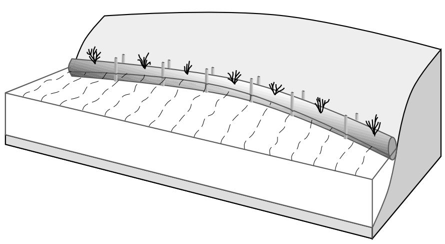
Applications and Effectiveness

- Form an immediate protective cover over the streambank.
- Capture sediment during flood flows.
- Provide opportunities for rooting of the cuttings over the streambank.
- Rapidly restores riparian vegetation and streamside habitat.
- Enhance conditions for colonization of native vegetation.
- Limited to the slope above base flow levels.
- Toe protection is required where toe scour is anticipated.
- Appropriate where exposed streambanks are threatened by high flows prior to vegetation establishment.
- Should not be used on slopes which are experiencing mass movement or other slope instability.

For More Information

- Consult the following references: Nos. 14, 21, 34, 56, 65, 77, 79, 81.

Coconut Fiber Roll



Cylindrical structures composed of coconut husk fibers bound together with twine woven from coconut material to protect slopes from erosion while trapping sediment which encourages plant growth within the fiber roll.

Applications and Effectiveness

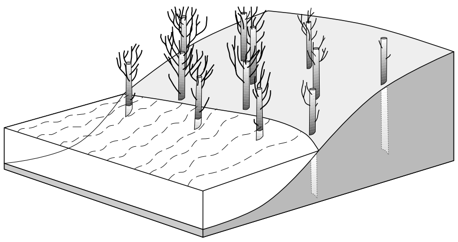
- Most commonly available in 12 inch diameter by 20 foot lengths.
- Typically staked near the toe of the streambank with dormant cuttings and rooted plants inserted into slits cut into the rolls.
- Appropriate where moderate toe stabilization is required in conjunction with restoration of the streambank and the sensitivity of the site allows for only minor disturbance.
- Provide an excellent medium for promoting plant growth at the water's edge.
- Not appropriate for sites with high velocity flows or large ice build up.
- Flexibility for molding to the existing curvature of the streambank.
- Requires little site disturbance.
- The rolls are buoyant and require secure anchoring.
- Can be expensive.
- An effective life of 6 to 10 years.
- Should, where appropriate, be used with soil bioengineering systems and vegetative plantings to stabilize the upper bank and ensure a regenerative source of streamside vegetation.
- Enhances conditions for colonization of native vegetation.

For More Information

- Consult the following references: Nos. 65, 77.

STREAMBANK TREATMENT

Dormant Post Plantings



Plantings of cottonwood, willow, poplar, or other species embedded vertically into streambanks to increase channel roughness, reduce flow velocities near the slope face, and trap sediment.

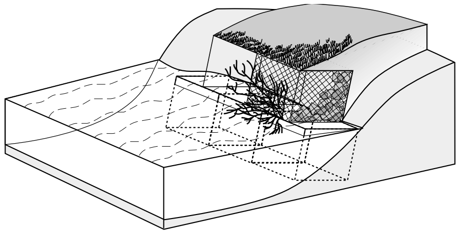
Applications and Effectiveness

- Can be used as live piling to stabilize rotational failures on streambanks where minor bank sloughing is occurring.
- Useful for quickly establishing riparian vegetation, especially in arid regions where water tables are deep.
- Will reduce near bank stream velocities and cause sediment deposition in treated areas.
- Reduce streambank erosion by decreasing the near-bank flow velocities.
- Generally self-repairing and will restem if attacked by beaver or livestock; however, provisions should be made to exclude such herbivores where possible.
- Best suited to non-gravely streams where ice damage is not a problem.
- Will enhance conditions for colonization of native species.
- Are less likely to be removed by erosion than live stakes or smaller cuttings.
- Should, where appropriate, be used with soil bioengineering systems and vegetative plantings to stabilize the upper bank and ensure a regenerative source of streamside vegetation.
- Unlike smaller cuttings, post harvesting can be very destructive to the donor stand, therefore, they should be gathered as 'salvage' from sites designated for clearing, or thinned from dense stands.

For More Information

- Consult the following references: Nos. 65, 77, 79.

Vegetated Gabions



Wire-mesh, rectangular baskets filled with small to medium size rock and soil and laced together to form a structural toe or sidewall. Live branch cuttings are placed on each consecutive layer between the rock filled baskets to take root, consolidate the structure, and bind it to the slope.

Applications and Effectiveness

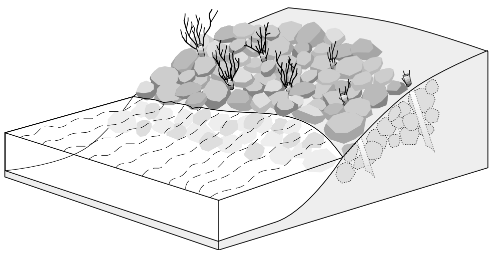
- Useful for protecting steep slopes where scouring or undercutting is occurring or there are heavy loading conditions.
- Can be a cost effective solution where some form of structural solution is needed and other materials are not readily available or must be brought in from distant sources.
- Useful when design requires rock size greater than what is locally available.
- Effective where bank slope is steep and requires moderate structural support.
- Appropriate at the base of a slope where a low toe wall is needed to stabilize the slope and reduce slope steepness.
- Will not resist large, lateral earth stresses.
- Should, where appropriate, be used with soil bioengineering systems and vegetative plantings to stabilize the upper bank and ensure a regenerative source of streambank vegetation.
- Require a stable foundation.
- Are expensive to install and replace.
- Appropriate where channel side slopes must be steeper than appropriate for riprap or other material, or where channel toe protection is needed, but rock riprap of the desired size is not readily available.
- Are available in vinyl coated wire as well as galvanized steel to improve durability.
- Not appropriate in heavy bedload streams or those with severe ice action because of serious abrasion damage potential.

For More Information

- Consult the following references: Nos. 11, 18, 34, 56, 77.

STREAMBANK TREATMENT

Joint Plantings



Live stakes tamped into joints or openings between rock which have previously been installed on a slope or while rock is being placed on the slope face.

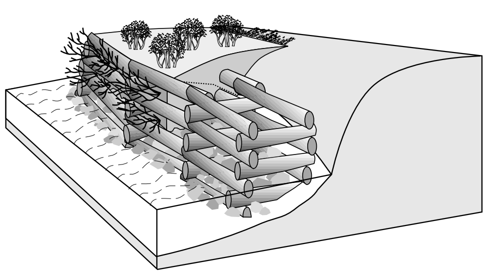
Applications and Effectiveness

- Appropriate where there is a lack of desired vegetative cover on the face of existing or required rock riprap.
- Root systems provide a mat upon which the rock riprap rests and prevents loss of fines from the underlying soil base.
- Root systems also improve drainage in the soil base.
- Will quickly establish riparian vegetation.
- Should, where appropriate, be used with other soil bioengineering systems and vegetative plantings to stabilize the upper bank and ensure a regenerative source of streambank vegetation.
- Have few limitations and can be installed from base flow levels to top of slope, if live stakes are installed to reach ground water.
- Survival rates can be low due to damage to the cambium or lack of soil/ stake interface.
- Thick rock riprap layers may require special tools for establishing pilot holes.

For More Information

- Consult the following references: Nos. 21, 34, 65, 77, 81.

Live Cribwalls



Hollow, box-like interlocking arrangements of untreated log or timber members filled above baseflow with alternate layers of soil material and live branch cuttings that root and gradually take over the structural functions of the wood members.

Applications and Effectiveness

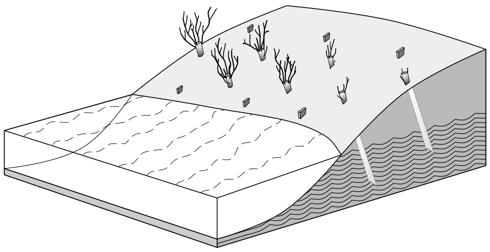
- Provide protection to the streambank in areas with near vertical banks where bank sloping options are limited.
- Afford a natural appearance, immediate protection and accelerate the establishment of woody species.
- Effective on outside of bends of streams where high velocities are present.
- Appropriate at the base of a slope where a low wall might be required to stabilize the toe and reduce slope steepness.
- Appropriate above and below water level where stable streambeds exist.
- Don't adjust to toe scour.
- Can be complex and expensive.
- Should, where appropriate, be used with soil bioengineering systems and vegetative plantings to stabilize the upper bank and ensure a regenerative source of streambank vegetation.

For More Information

- Consult the following references: Nos. 11, 14, 21, 34, 56, 65, 77, 81.

STREAMBANK TREATMENT

Live Stakes



Live, woody cuttings which are tamped into the soil to root, grow and create a living root mat that stabilizes the soil by reinforcing and binding soil particles together, and by extracting excess soil moisture.

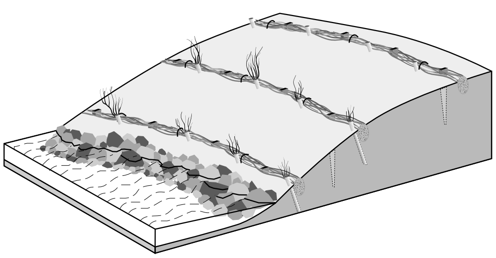
Applications and Effectiveness

- Effective where site conditions are uncomplicated, construction time is limited, and an inexpensive method is needed.
- Appropriate for repair of small earth slips and slumps that are frequently wet.
- Can be used to stake down surface erosion control materials.
- Stabilize intervening areas between other soil bioengineering techniques.
- Rapidly restores riparian vegetation and streamside habitat.
- Should, where appropriate, be used with other soil bioengineering systems and vegetative plantings.
- Enhance conditions for colonization of vegetation from the surrounding plant community.
- Requires toe protection where toe scour is anticipated.

For More Information

- Consult the following references: Nos. 14, 21, 34, 56, 65, 67, 77, 79, 81.

Live Fascines



Dormant branch cuttings bound together into long sausage-like, cylindrical bundles and placed in shallow trenches on slopes to reduce erosion and shallow sliding.

Applications and Effectiveness

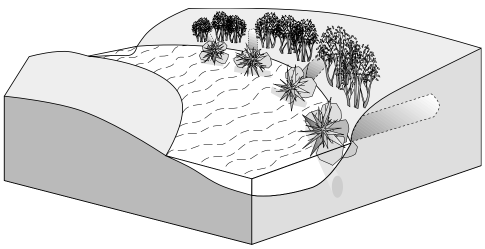
- Can trap and hold soil on streambank by creating small dam-like structures and reducing the slope length into a series of shorter slopes.
- Facilitate drainage when installed at an angle on the slope.
- Enhance conditions for colonization of native vegetation.
- Should, where appropriate, be used with other soil bioengineering systems and vegetative plantings.
- Requires toe protection where toe scour is anticipated.
- Effective stabilization technique for streambanks, requiring a minimum amount of site disturbance.
- Not appropriate for treatment of slopes undergoing mass movement.

For More Information

- Consult the following references: Nos. 14, 21, 34, 65, 77, 81.

STREAMBANK TREATMENT

Log, Rootwad, and Boulder Revetments



Boulders and logs with root masses attached placed in and on streambanks to provide streambank erosion, trap sediment, and improve habitat diversity.

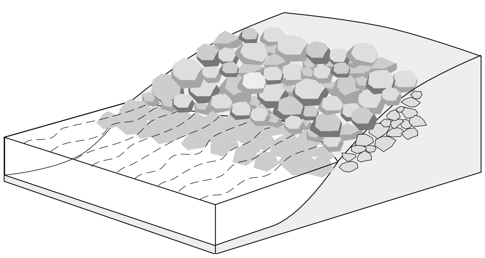
Applications and Effectiveness

- Will tolerate high boundary shear stress if logs and rootwads are well anchored.
- Suited to streams where fish habitat deficiencies exist.
- Should, where appropriate, be used with soil bioengineering systems and vegetative plantings to stabilize the upper bank and ensure a regenerative source of streambank vegetation.
- Will enhance diversity in riparian areas when used with soil bioengineering systems.
- Will have limited life depending on climate and tree species used. Some species, such as cottonwood or willow, often sprout and accelerate colonization.
- Might need eventual replacement if colonization does not take place or soil bioengineering systems are not used.
- Use of native materials can sequester sediment and woody debris, restore streambanks in high velocity streams, and improve fish rearing and spawning habitat.
- Site must be accessible to heavy equipment.
- Materials might not be readily available at some locations.
- Can create local scour and erosion.
- Can be expensive.

For More Information

- Consult the following references: Nos. 11, 34, 77.

Riprap



A blanket of appropriately sized stones extending from the toe of slope to a height needed for long term durability.

Applications and Effectiveness

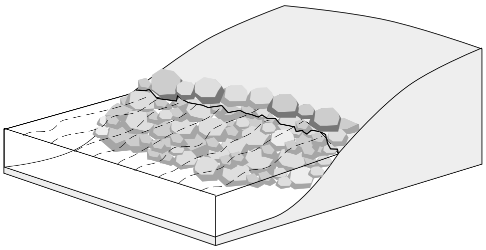
- Can be vegetated (see joint plantings).
- Appropriate where long term durability is needed, design discharge are high, there is a significant threat to life or high value property, or there is no practical way to otherwise incorporate vegetation into the design.
- Should, where appropriate, be used with soil bioengineering systems and vegetative plantings to stabilize the upper bank and ensure a regenerative source of streambank vegetation.
- Flexible and not impaired by slight movement from settlement or other adjustments.
- Should not be placed to an elevation above which vegetative or soil bioengineering systems are an appropriate alternative.
- Commonly used form of bank protection.
- Can be expensive if materials are not locally available.

For More Information

- Consult the following references: Nos. 11, 14, 18, 34, 39, 56, 67, 70, 77.

STREAMBANK TREATMENT

Stone Toe Protection



A ridge of quarried rock or stream cobble placed at the toe of the streambank as an armor to deflect flow from the bank, stabilize the slope and promote sediment deposition.

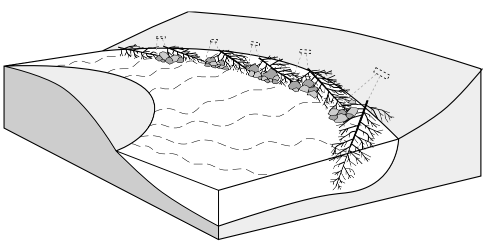
Applications and Effectiveness

- Should be used on streams where banks are being undermined by toe scour, and where vegetation cannot be used.
- Stone prevents removal of the failed streambank material that collects at the toe, allows revegetation and stabilizes the streambank.
- Should, where appropriate, be used with soil bioengineering systems and vegetative plantings to stabilize the upper bank and ensure a regenerated source of streamside vegetation.
- Can be placed with minimal disturbance to existing slope, habitat, and vegetation.

For More Information

- Consult the following references: Nos. 10, 21, 56, 67, 77, 81.

Tree Revetments



A row of interconnected trees attached to the toe of the streambank or to deadmen in the streambank to reduce flow velocities along eroding streambanks, trap sediment, and provide a substrate for plant establishment and erosion control.

Applications and Effectiveness

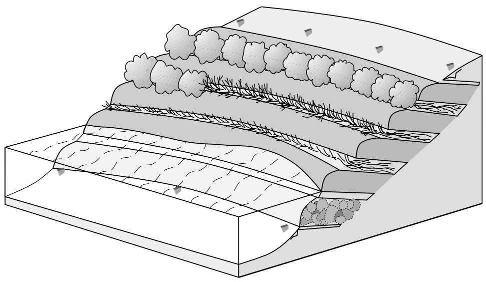
- Design of adequate anchoring systems is necessary.
- Wire anchoring systems can present safety hazards.
- Work best on streams with streambank heights under 12 feet and bankfull velocities under 6 feet per second.
- Use inexpensive, readily available materials.
- Capture sediment and enhances conditions for colonization of native species particularly on streams with high bed material loads.
- Limited life and must be replaced periodically.
- Might be severely damaged by ice flows.
- Not appropriate for installation directly upstream of bridges and other channel constrictions because of the potential for downstream damages should the revetment dislodge.
- Should not be used if they occupy more than 15 percent of the channel's cross sectional area at bankfull level.
- Not recommended if debris jams on downstream bridges might cause subsequent problems.
- Species that are resistant to decay are best because they extend the establishment period for planted or volunteer species that succeed them.
- Requires toe protection where toe scour is anticipated.
- Should, where appropriate, be used with soil bioengineering systems and vegetative plantings to stabilize the upper bank and ensure a regenerated source of streamside vegetation.

For More Information

- Consult the following references: Nos. 11, 21, 34, 56, 60, 77, 79.

STREAMBANK TREATMENT

Vegetated Geogrids



Alternating layers of live branch cuttings and compacted soil with natural or synthetic geotextile materials wrapped around each soil lift to rebuild and vegetate eroded streambanks.

Applications and Effectiveness

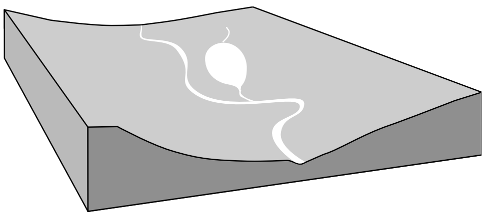
- Quickly establish riparian vegetation if properly designed and installed.
- Can be installed on a steeper and higher slope and has a higher initial tolerance of flow velocity than brush layering.
- Can be complex and expensive.
- Produce a newly constructed, well-reinforced streambank.
- Useful in restoring outside bends where erosion is a problem.
- Capture sediment and enhances conditions for colonization of native species.
- Slope stability analyses are recommended.
- Can be expensive.
- Require a stable foundation.

For More Information

- Consult the following references: Nos. 10, 11, 14, 21, 34, 56, 65, 77.

WATER MANAGEMENT

Sediment Basins



Barriers, often employed in conjunction with excavated pools, constructed across a drainage way or off-stream and connected to the stream by a flow diversion channel to trap and store waterborne sediment and debris.

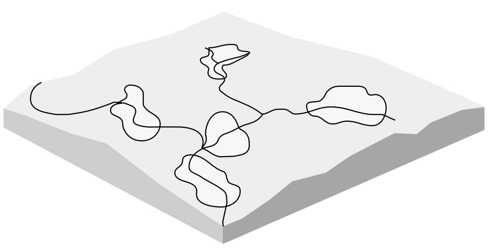
Applications and Effectiveness

- Provide an interim means of reducing the sediment load from a stream.
- Used occasionally to sort sediment sizes.
- Temporarily reduce excessive sediment loads until the upstream watershed can be protected from accelerated erosion.
- Can also be used to separate out sediment which may be causing damages downstream along reaches which are incapable of transporting the sediment sizes.
- Can be integrated with more permanent stormwater management ponds.
- Can only trap the upper range of particle sizes (sand and gravel) and allow finer particles (silt and clay) to pass through.
- Require a high level of analysis.
- Require periodic dredging and other maintenance.

For More Information

- Consult the following references: Nos. 10, 13, 29, 45, 49, 69, 74, 80.

Water Level Control



Managing water levels within the channel and adjoining riparian zone to control aquatic plants and restore desired functions, including aquatic habitat.

Applications and Effectiveness

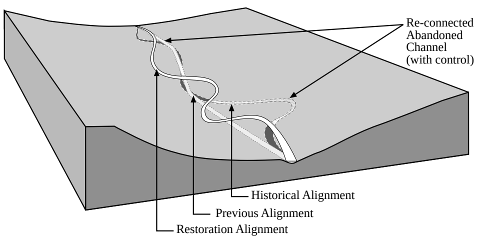
- Appropriate where flow depth in the stream, adjoining wetland, or the interdependent saturation zone in the adjoining riparian area is insufficient to provide desired functions.
- Need will often vary by season and requires flexible control devices which can be managed accordingly.
- The complexities of maintaining sediment balances, temperature elevation, change in channel substrate, changes in flow regime, and a host of other considerations must be factored into planning and design.
- Requires a high level of analysis.

For More Information

- Consult the following references: Nos. 11, 13, 15, 69, 75.

CHANNEL RECONSTRUCTION

Maintenance of Hydraulic Connections



Maintenance of hydraulic connectivity to allow movement of water and biota between the stream and abandoned channel reaches.

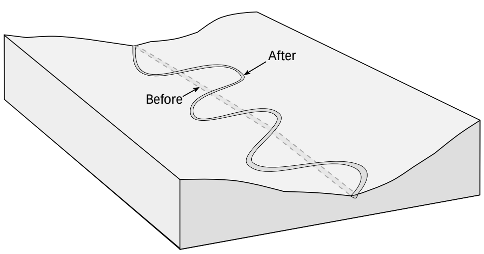
Applications and Effectiveness

- Used to prevent losses of aquatic habitat area and diversity.
- Slackwater areas adjoining the main channel have potential for spawning and rearing areas for many fish species and are a key component of habitat for wildlife species that live in or migrate through the riparian corridor.
- Recreation value can be enhanced if connecting channels are deep enough for small boats or canoes.
- Effective along reaches of realigned channel where cutoffs have been made.
- Not effective in streams with insufficient stages or discharges to maintain satisfactory hydraulic connections to the abandoned channel reaches.
- May require maintenance if sedimentation is a problem.
- May have limited life.
- Require a high level of analysis.

For More Information

- Consult the following references: Nos. 15, 56, 69, 75.

Stream Meander Restoration



Transformation of a straightened stream into a meandering one to reintroduce natural dynamics improve channel stability, habitat quality, aesthetics, and other stream corridor functions or values.

Applications and Effectiveness

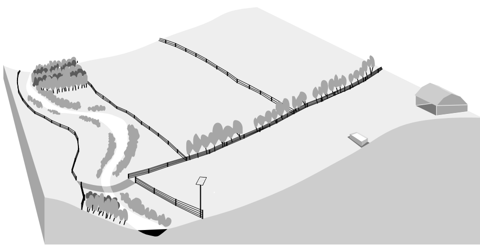
- Used to create a more stable stream with more habitat diversity.
- Requires adequate area where adjacent land uses may constrain locations.
- May not be feasible in watersheds experiencing rapid changes in land uses.
- Streambank protection might be required on the outside of bends.
- Significant risk of failure.
- Requires a high level of analysis.
- May cause significant increases in flood elevations.
- Effective discharge should be computed for both existing and future conditions, particularly in urbanized watersheds.

For More Information

- Consult the following references: Nos. 13, 16, 22, 23, 24, 46, 47, 52, 53, 54, 56, 61, 72, 75, 77, 78, 79, 86.

STREAM CORRIDOR MEASURES

Livestock Exclusion or Management



Fencing, alternate sources of water and shelter, and managed grazing to protect, maintain, or improve riparian flora and fauna and water quality.

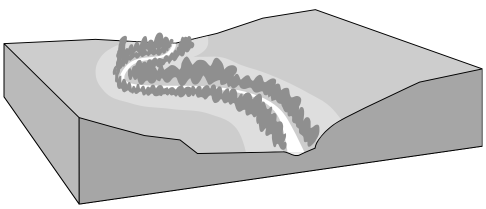
Applications and Effectiveness

- Appropriate where livestock grazing is negatively impacting the stream corridor by reducing growth of woody vegetation, decreasing water quality, or contributing to the instability of streambanks.
- Once the system has recovered, rotational grazing may be incorporated into the management plan.
- Must be coordinated with an overall grazing plan.

For More Information

- Consult the following references: Nos. 18, 39, 73.

Riparian Forest Buffers



Streamside vegetation to lower water temperatures, provide a source of detritus and large woody debris, improve habitat, and to reduce sediment, organic material, nutrients, pesticides and other pollutants migrating to the stream.

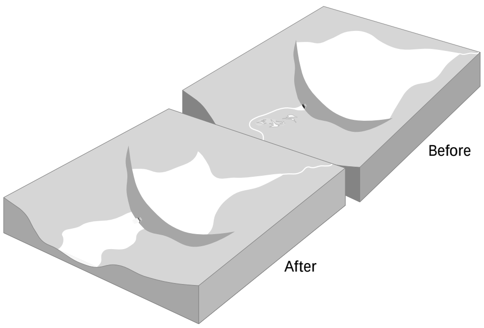
Applications and Effectiveness

- Applicable on stable areas adjacent to permanent or intermittent streams, lakes, ponds, wetlands and areas with ground water recharge.
- Unstable areas such as those with high surface erosion rates, mass soil movement, or active gullies will require stabilization prior to establishment of riparian forest buffers.
- Tolerant plant species and supplemental watering may be needed in some areas.
- Sites in arid and semi-arid regions may not have sufficient soil moisture throughout the growing season to support woody plants.
- Concentrated flow erosion, excessive sheet and rill erosion, or mass soil movement must be controlled in upland areas prior to establishment of riparian forest buffers.

For More Information

- Consult the following references: Nos. 20, 34, 49, 51, 70, 78, 79, 81, 82, 88, 89.

Flushing for Habitat Restoration



A high-magnitude, short duration release from a reservoir to scour fine-grained sediments from the streambed and restore suitable instream habitat.

Applications and Effectiveness

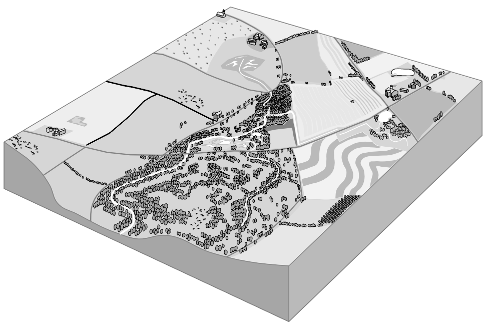
- Appropriate as part of an overall watershed management plan.
- May cause flooding of old floodplains below dams, depletion of gravel substrates, and significant changes in channel geometry.
- Flushing of fine sediments at one location may only move the problem further downstream.
- Seasonal discharge limits, rate of change of flow, and river stages downstream of impoundment should be considered to avoid undesirable impacts to instream and riparian habitat.
- Can be effective in improving gradation of streambed materials, suppression of aquatic vegetation, and maintenance of stream channel geometry necessary for desired instream habitat.
- Can induce floodplain scouring to provide suitable growing conditions for riparian vegetation.
- Requires high level of analysis to determine necessary release schedule.
- May not be feasible in areas where water rights are fully allocated.

For More Information

- Consult the following references: Nos. 11, 13, 32, 35, 41, 45, 57, 61, 73, 74, 81.

WATERSHED MANAGEMENT

Best Management Practices: Agriculture



Individual and systematic approaches aimed at mitigating non-point source pollution from agricultural land.

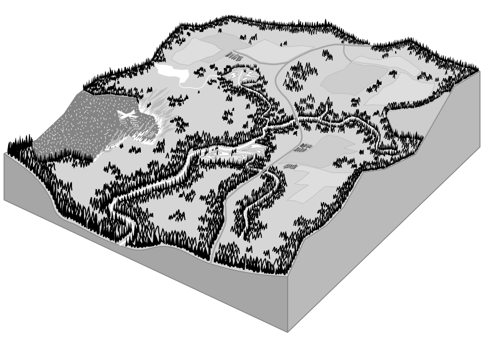
Applications and Effectiveness

- Used where current management systems are causing problems on-site or within farm or field boundaries and have a high potential to impact the stream corridor.
- Also applied where watershed management plans are being implemented to improve environmental conditions.
- Must fit within a comprehensive farm management plan, a watershed action plan, or a stream corridor restoration plan.
- Should consider the four season conservation of the soil, water, and microbial resources base.
- Tillage, seeding, fertility, pest management, and harvest operations should consider environmental qualities and the potential to use adjacent lands in water and soil conservation and management and pest management.
- Grazing land management should protect environmental attributes, including native species protection, while achieving optimum, long-term resource use.
- Where crops are raised and the land class allows, pastures should be managed with crop rotation sequences to provide vigorous forage cover while building soil and protecting water and wildlife qualities.
- Orchards and nursery production should actively monitor pest and water management techniques to protect ecosystem quality and diversity.
- Farm woodlots, wetlands, and field borders should be part of an overall farm plan that conserves, protects, and enhances native plants and animals, soil, water, and scenic qualities.
- BMPs may include: contour farming, conservation tillage, terracing, critical area planting, nutrient management, sediment basins, filter strips, waste storage management, and integrated pest management.

For More Information

- Consult the following references: Nos. 73, 78, 81.

Best Management Practices: Forestland



Individual and systematic approaches for mitigating non-point source pollution from forestland.

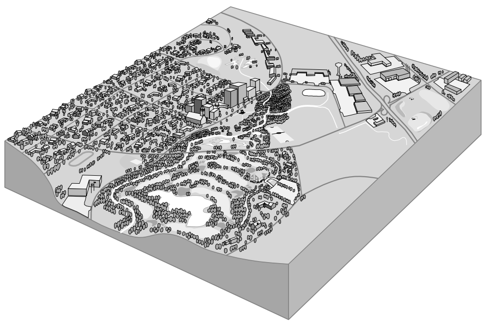
Applications and Effectiveness

- Used where current management systems are causing problems in the watershed and have a high potential to impact the stream corridor.
- Also applied where management plans are being implemented to restore one or more natural resource functions in a watershed.
- Must consider how it fits within a comprehensive forestland management plan, a watershed action plan, or a stream corridor restoration plan.
- BMPs may include: preharvest planning, streamside management measures, road construction or reconstruction, road management, timber harvesting, site preparation and forest generation, fire management, revegetation of disturbed areas, forest chemical management, and forest wetland management.

For More Information

- Consult the following references: Nos. 9, 20, 27, 30, 34, 42, 49, 51, 70, 78, 79, 81, 82, 83, 88, 89.

Best Management Practices: Urban Areas



Individual or systematic approaches designed to offset, reduce, or protect against the impacts of urban development and urban activities on the stream corridor.

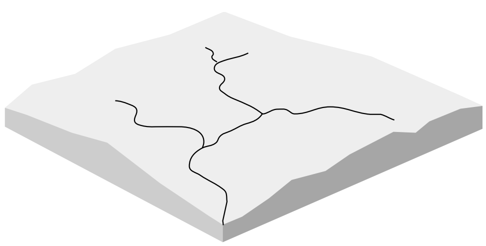
Applications and Effectiveness

- Used to improve and/or restore ecological functions which have been impaired by urban activities.
- Needs to be integrated with BMPs on other lands in the landscape to assure that stream restoration is applied along the entire stream corridor to the extent possible.
- The use of individual urban BMPs should be coordinated with an overall plan for restoring the stream system.
- Urban sites are highly variable and have a high potential for disturbance.
- Applicability of the treatment to the site situation in terms of physical layout, relationship to the overall system, arrangements for maintenance, and protection from disturbances are often critical considerations.
- BMPs may include: extended detention dry basins, wet ponds, constructed wetlands, oil-water separators, vegetated swales, filter strips, infiltration basins and trenches, porous pavement, and urban forestry.

For More Information

- Consult the following references: Nos. 29, 34, 43, 49, 78, 80, 81, 83.

Flow Regime Enhancement



Manipulation of watershed features (such as changes in land use or construction of impoundments) for the purpose of controlling streamflow and improving physical, chemical and biological functions.

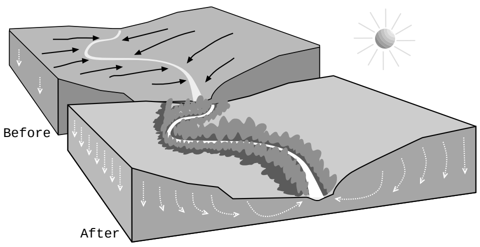
Applications and Effectiveness

- Appropriate where human-induced changes have altered stream flow characteristics to the extent that streams no longer support their former functions.
- Can restore or improve threatened functions (e.g., substrate materials or distribution of flow velocities to support the natural food web).
- Can require extensive changes over broad areas involving many land users.
- Can be expensive.
- Has been used for remediation of depleted dissolved oxygen levels, reduction in salinity levels, or to maintain a minimum flow level for downstream users.
- Must determine what impacts from historical changes in the flow regime over time can be mitigated using flow enhancement techniques.

For More Information

- Consult the following references: Nos. 32, 39, 45, 57, 75, 81.

Streamflow Temperature Management



Streamside vegetation and upland practices to reduce elevated streamflow temperatures.

Applications and Effectiveness

- Effective for smaller streams where bank vegetation can provide substantial shading of the channel and on which much of the canopy has been removed.
- Appropriate practices are those that establish streamside vegetation, increase vegetative cover, increase infiltration and subsurface flow, maintain base flow, and reduce erosion.
- Turbid water absorbs more solar radiation than clear; therefore, erosion control in watersheds can help in reducing thermal pollution.
- Flow releases from cooler strata of reservoirs must be exercised with caution. Although cooler, water from this source is generally low in dissolved oxygen and must be aerated before discharging downstream. Selective mixing of the reservoir withdrawal can moderate temperature as may be required.
- There might be opportunities in irrigated areas to cool return flows prior to discharge to streams.

For More Information

- Consult the following references: Nos. 32, 39, 45, 73, 80, 81, 88, 89.

Appendix A: List of References

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Appendix B

INCH-POUND / METRIC CONVERSION FACTORS

Length

Unit of measure	Abbreviation	mm	cm	m	km	in	ft	mi
millimeter	mm	1	0.1	0.001	—	0.0394	0.003	—
centimeter	cm	10	1	0.01	—	0.394	0.033	—
meter	m	1000	100	1	0.001	39.37	3.281	—
kilometer	km	—	—	1000	1	—	3281	0.621
inch	in	25.4	2.54	0.0254	—	1	0.083	—
foot	ft	304.8	30.48	0.305	—	12	1	—
mile	mi	—	—	1609	1.609	—	5280	1

Area

Unit of measure	Abbreviation	m^2	ha	km^2	ft^2	acre	mi^2
square meter	m^2	1	—	—	10.76	—	—
hectare	ha	10000	1	0.01	107600	2.47	0.00386
square kilometer	km^2	$1x10^6$	100	1	—	247	0.386
square foot	ft^2	0.093	—	—	1	—	—
acre	acre	4050	0.405	—	43560	1	0.00156
square mile	mi^2	—	259	2.59	—	640	1

Volume

Unit of measure	Abbreviation	km^3	m^3	L	Mgal	acre-ft	ft^3	gal
cubic kilometer	km^3	1	$1x10^9$	—	—	811000	—	—
cubic meter	m^3	—	1	1000	—	—	35.3	264
liter	L	—	0.001	1	—	—	0.0353	0.264
million U.S. gallons	Mgal	—	—	—	1	3.07	134000	$1x10^6$
acre-foot	acre-ft	—	1233	—	0.3259	1	43560	325848
cubic foot	ft^3	—	0.0283	28.3	—	—	1	7.48
gallon	gal	—	—	3.785	—	—	0.134	1

Flow Rate

Unit of measure	Abbreviation	km^3/yr	m^3/s	L/s	mgd	gpm	cfs	acre-ft/day
cubic kilometers/year	km^3/yr	1	31.7	—	723	—	1119	2220
cubic meters/second	m^3/s (m^3/sec)	0.0316	1	1000	22.8	15800	35.3	70.1
liters/second	L/s (L/sec)	—	0.001	1	0.0228	15.8	0.0353	0.070
million U.S. gallons/day	mgd (Mgal/d)	—	0.044	43.8	1	694	1.547	3.07
U.S. gallons/minute	gpm (gal/min)	—	—	0.063	—	1	0.0022	0.0044
cubic feet/second	cfs (ft^3/s)	—	0.0283	28.3	0.647	449	1	1.985
acre-feet/day	acre-ft/day	—	—	14.26	0.326	226.3	0.504	1

Temperature

Unit of measure	Abbreviation	F	C
Fahrenheit	F	—	.56 (after subtracting 32)
Celsius	C	1.8 (then add 32)	—