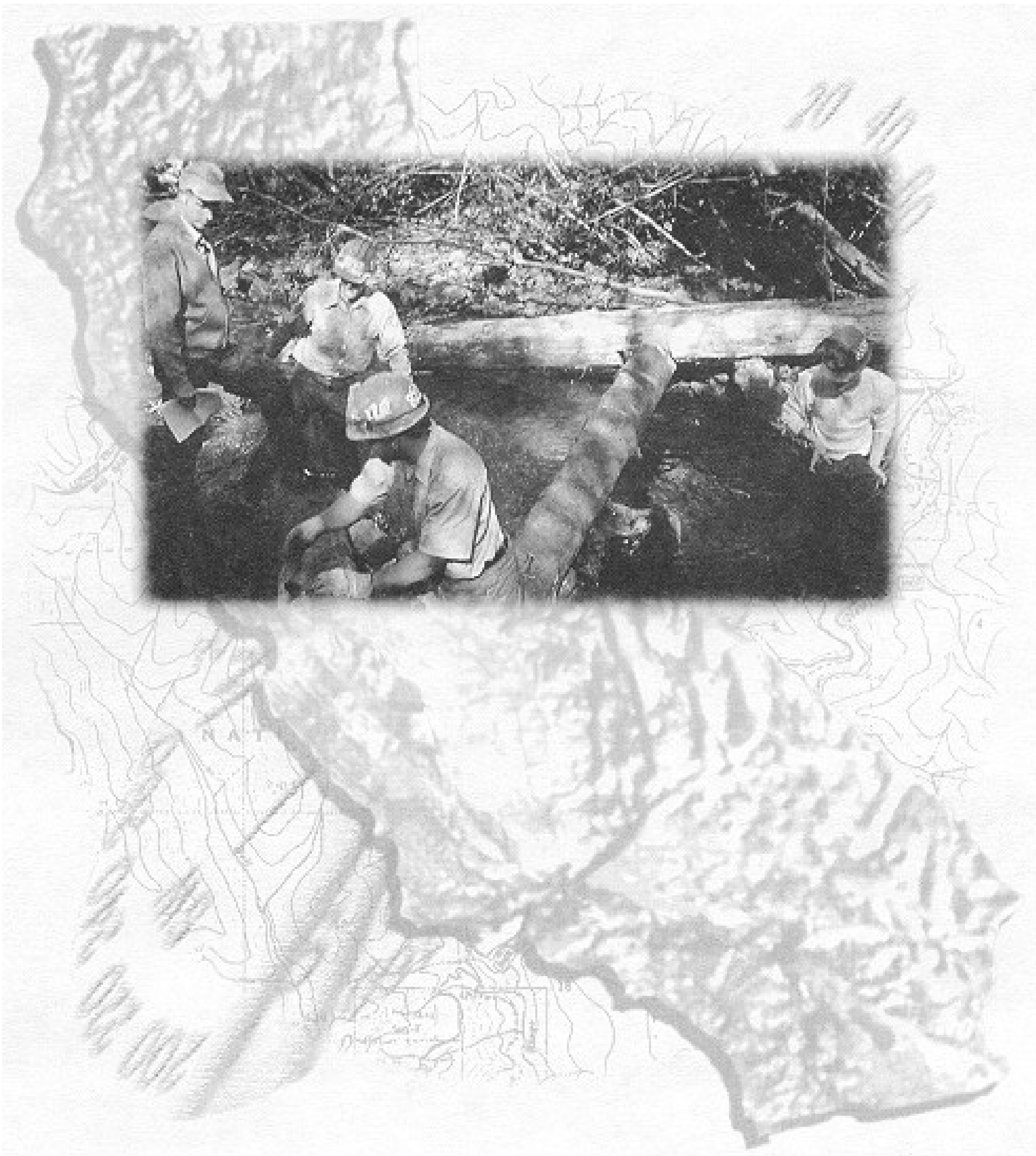
CALIFORNIA SALMONID STREAM HABITAT RESTORATION MANUAL

PART VII

PROJECT IMPLEMENTATION



PART VII PROJECT IMPLEMENTATION

When critical habitat has been determined to be lacking, placement of suitable structures or other remedial actions may be appropriate. If structural options are selected, some essential physical parameters must be considered. Project location and access, available structural materials, stream flow volume and velocity, current and expected land use practices, watershed stability, stream channel and bank stability, and bedload and debris transport are basic parameters that must be considered before instream improvement structures are installed. Hydraulic cross sectional analysis should always be performed to assure passage of bankfull flows.

Kinetic energy of a stream determines its ability to move materials. Maximum kinetic energy is generated during bankfull flow, usually related to storms. Bankfull flows may also occur because of released storage in regulated streams. It is during these bankfull flow events that maximum bedload transport and channel formation occurs. As flows subside, deposition and additional stream channel forming processes occur.

Numerous factors including watershed condition, channel configuration, and instream structure regulate bedload transport through a system. The coupling of water energy and bedload limits the opportunities for placement of stable fish habitat structures.

SELECTION OF STABLE SITES

Stable habitat restoration sites with appropriate hydrologic channel characteristics afford the greatest opportunity for successful structure installation. Review of site suitability for project work must incorporate an assessment of natural features of the stream. For example, observation of deposition and scour areas on stream banks will reveal the range of flows in the stream. At each potential structure site, the following factors should be analyzed to determine if a structure will be suitable, stable, and effective.

Gradient

For many structures, sites with gradients less than 0.5 percent or greater than four percent are poor candidates. Stream reaches with gradients of less than 0.5 percent are frequently depositional areas. Partial channel spanning structures that constrict flow such as single and opposing wing deflectors or constricting weirs, can be used to increase water velocities, creating habitat by deepening channels.

High gradient stream reaches greater than four percent are difficult to control. The substrate in these streams is often bedrock or boulder and usually lacks spawning gravel. Full channel spanning structures designed to trap gravel must be placed very close together to reduce the flushing effect of high stream flow velocity. Hydraulic forces present in excessively high gradient streams increase stress and the probability of structural failure, and reduces the number of alternative treatments and the chance of a project succeeding.

Stream Width

Sites in reaches that are slightly wider than mean stream width are the best candidates for successful channel spanning structures. Velocities in these areas will be lower than more constricted reaches, providing a natural energy control. However, overly wide channels will typically be areas of deposition and are unsuitable for other than channel constricting structures.

Substrate

Bedload deposition tends to occur in areas of mean stream width or wider. These areas provide the greatest opportunity for placement of substrate scour or deposition structures. Channel spanning structures may be placed to capture gravel or other bedload materials on the upstream side of the structure, and create scour downstream. A series of structures can redistribute bedload and create reaches containing gravel deposition, cover, and scoured pools. Free-standing structures are typically unstable because of periodic bedload movement associated with high flows.

Highly compacted substrate creates special construction problems for placement of instream fish habitat structures. Heavy equipment or specialized techniques may be required to securely anchor structures at these sites. For this reason, construction costs are often prohibitive and long term stability is uncertain.

Bedrock substrate provides a good anchor for instream structures using cable or rebar and polyester resin adhesive. The bedrock foundation for a stable structure must be un-fractured and durable.

Stream Order

Lower order streams, at appropriate sites, can usually be controlled with standard habitat restoration structures. Higher order streams typically have high stream power and require large construction materials and larger or more complex structures, making site selection even more critical.

Reach Length

Generally, a reach should be long enough so that structures can be placed in a series. When structures are placed in a series, the most upstream and downstream structures create velocity control points. These controls can be particularly important in areas where deposition of gravel is the purpose of the structure.

Channel Sinuosity

Sinuous stream reaches are areas of scour and deposition. To be effective in these reaches, a structure must be fitted to the bend in the stream. For example, diagonal weirs located on a bend will trap gravel while downstream-V weirs at the same site generally will not. Generally, sinuous stream reaches are not desirable locations for structures built in a series.

Bank Stability

The choice of suitable structures is limited by the stability of stream banks at the site. For example, structures that direct flow into unstable banks will result in bank erosion and possible structural failure. Stable banks are essential to structural integrity in channel spanning structures.

Bank Morphology

Stability of habitat structures will be affected by stream bank morphology. Especially steep banks will result in rapidly rising stream surface elevation with increased flows overtopping installed structures. Unconfined stream banks will result in rapid widening of the stream, with increased flows potentially relocating the stream channel and circumventing the structure. Bedrock or well consolidated stream banks provide a stable base for structure placement, whereas poorly consolidated stream banks require riprap or other durable material for protection.

The extent to which boulders and woody structures protrude from the stream bank into the channel will provide a reasonably good guideline for placement of stream bank associated habitat structures. For comparative purposes, look at natural channel features that presently produce habitat similar to that which needs to be increased. Projects should use successful natural features as guidelines for design and location of structures whenever possible.

HYDRAULIC IMPACTS

A familiarity with the principles of stream hydraulics is important when designing site specific instream habitat enhancement structures because it is necessary to predict hydraulic impacts of each project to ensure that it will achieve the desired result. Inter-Fluve Inc. has developed a method for predicting hydraulic impacts, "Using Basic Hydraulic Analysis for In-Channel Design" (G. Koonce and M. Kiesse, Inter-Fluve Inc., personal communication). However, due to the myriad of factors affecting streams it remains difficult to measure and predict the precise outcome of a new structure to a stream. Evaluation of each project site for successes, failures, and causes is useful for developing skills of selection, design, and construction of habitat improvement structures.

For any single structure such as a diagonal log weir, the location of stream scour and deposition is relatively predictable. As structures become more complex, or a series of structures is developed, scour and deposition becomes more difficult to predict.

Scour is predictable at four locations in a stream: on the outside of bends, below waterfalls or cascades, at a constriction, or at a steepened gradient. The amount of scour generated by a structure has built-in limitations controlled by the kinetic energy budget of the stream.

Similarly, deposition can be predicted at three locations in a stream: on the inside of bends, in quiet water areas such as eddies where stream energy has been dissipated, and on the upstream side of natural sills or structures where flow is obstructed.

Height of a structure or relative radius of a bend influences the amount of scour or deposition. For example, stream flow and energy gradient, combined with effective height of a structure will dictate the depth of scour. In general, the higher the structure the deeper the plunge, up to the point of energy limitations (Figure VII-1). The need for upstream migration of adults or juveniles is a very important consideration when deciding how high to build a structure. Jumps in excess of 12 inches are to be avoided. If the gradient of the stream dictates a structure of over 12 inches in height, a low-flow notch at the thalweg is required to improve upstream migration for juveniles.

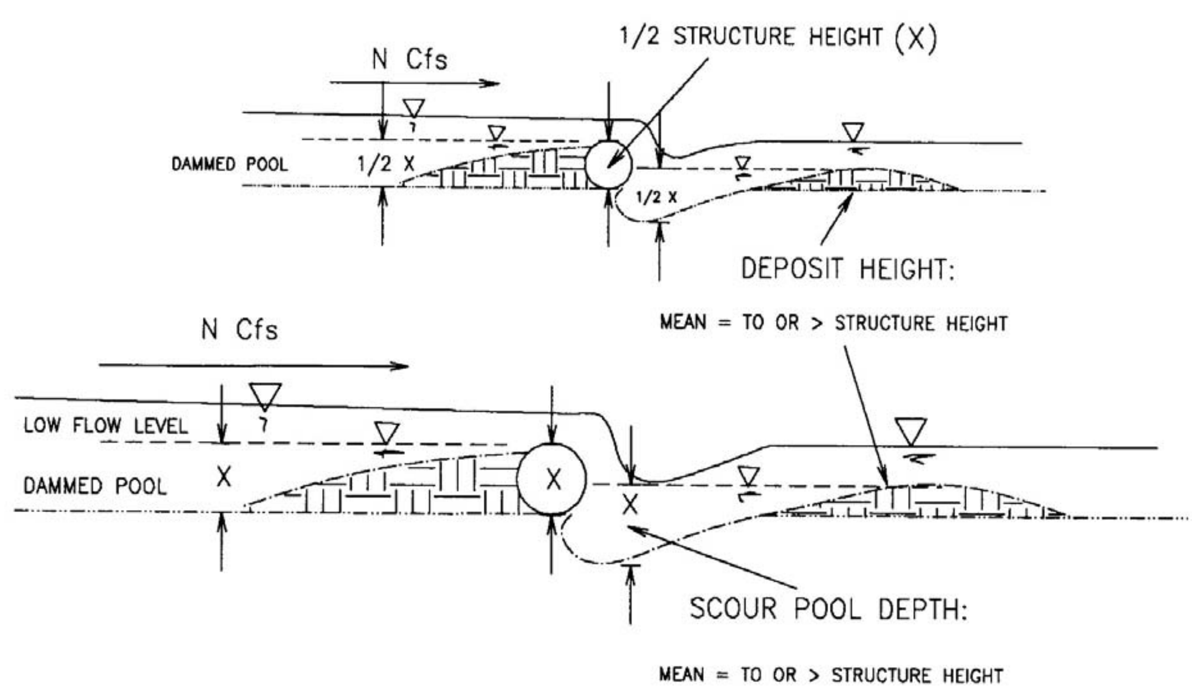


Figure VII-1. Typical structures of variable height in the same stream reach create pool depths and deposition heights directly related to structural heights (Anderson, 1988).

Without attempting formal hydraulic engineering analysis, observation of an existing structure in a stream will give a good indication of the scour that can be expected for a similar structure. Structures that obstruct flow tend to produce bars downstream that are nearly as tall as the structure.

Where water overtops a structure, the vertical angle of the downstream face strongly influences potential stability of the structure by directing the impact of the plunge flow. A vertical face will result in scour directly at the toe and may undercut the structure. With some designs of log structures this may be desirable but for boulder structures in deep alluvial streams this may result in structure failure. Undercutting can be avoided by placement of downstream rows of successively deeper boulders to provide a sloping face (Figure VII-2) that directs plunge flow away from the structure.

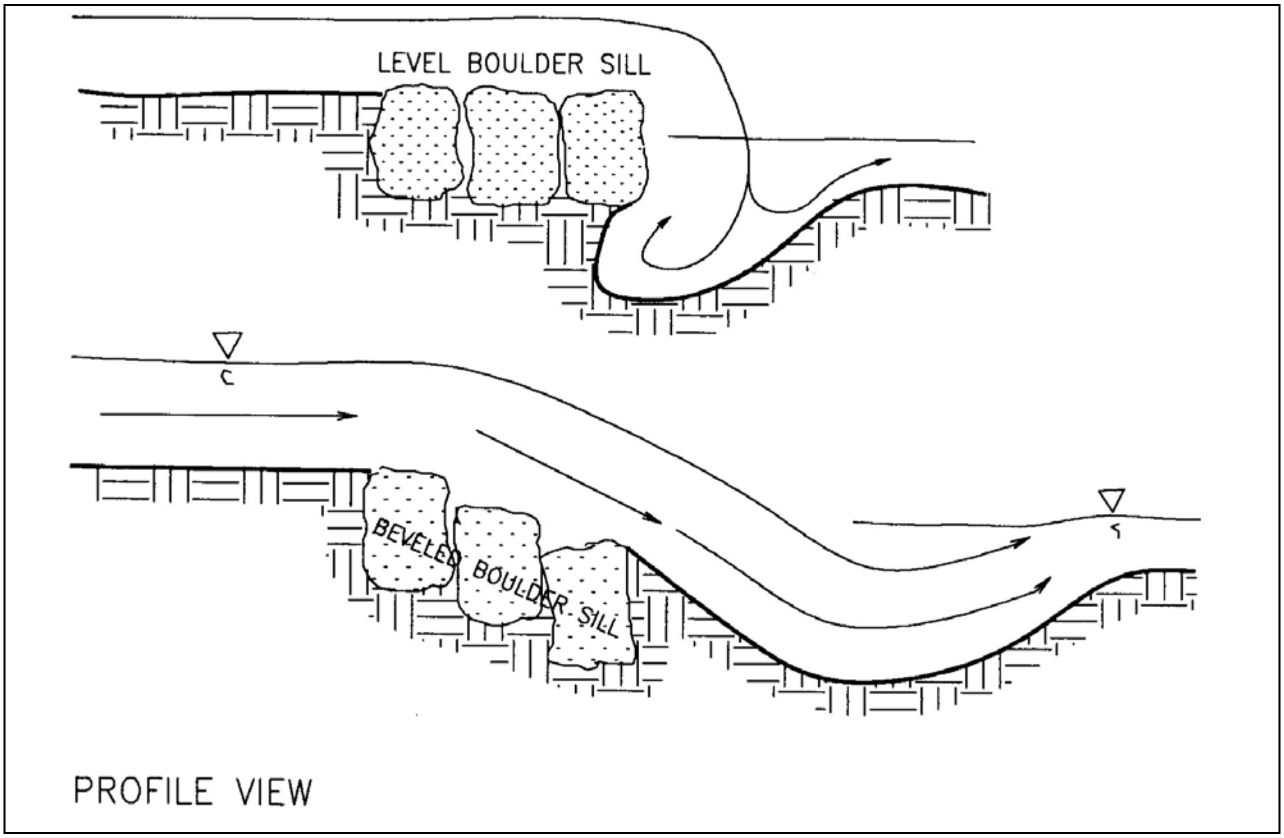


Figure VII-2. Comparison of level and sloping boulder face affect on flow into plunge pool (Overton, 1987).

Length of a full-spanning structure relative to the perpendicular stream width affects the stream's energy budget above and below the structure. Structures perpendicular to flow, such as straight log weirs, generally increase velocities because they narrow the high-flow channel. This happens because of the constriction created by the anchoring structures required to protect the ends of the weir. Structures such as diagonal log weirs that are two to three times the mean stream width will widen the hydraulic cross section, thus decreasing velocities.

Structures placed level on stream grade will produce even cross-sectional flows with very predictable deposition areas above and below the structure. Structures of irregular heights will break up these even flows and produce irregular scour and deposition areas. Although structures of irregular height are not as stable as those placed level, they can enhance salmonid spawning and rearing by increasing diversity of cover in the form of turbulence and scoured pools. The simpler the design the more likely it will be that hydraulic impacts can be forecast. It is more difficult to reliably predict the outcome of complex structural arrangements largely because of multiple and unequal flow vectors generated.

Channel constrictions are common natural occurrences and can be easily duplicated with structures. Bedload is moved through the constricted area and scour is created and maintained within the constraints of the available kinetic energy budget. Structures such as upstream-V weirs, and single and opposing wing-deflectors are examples of channel constrictors. A channel can also be widened to spread out the flow and diminish concentration of energy. This usually will result in channel aggradation. Downstream-V weirs and diagonal weirs are common structures for this purpose.

Multiple structures placed in a stream reach or complex structures such as log, root wad, and boulder combinations can create complex habitat with a wide variety of habitat niches.

SELECTION OF MATERIALS

The site often dictates which types of materials and which techniques must be used to successfully accomplish a stream habitat enhancement project. Selection of materials should come only after considering all factors. Factors to consider include:

- What are project objectives?
- What are funding limitations?
- What is expected life of the structure?
- What materials are on-site or nearby?
- If materials must be imported, are they economically available in adequate quality and quantity?
- Can the material of choice successfully be held in place during a major hydrological event?
- Will placement of enhancement structures require mechanized equipment, a large work crew or a combination?
- Are there access roads to the project site or a feasible way to get equipment and materials to the stream?
- Are the materials of choice aesthetically acceptable?

These considerations, together with the following information should be useful for choosing appropriate materials for fish habitat improvement structures.

Basic Structural Materials

Gabions

Gabions are heavy wire-mesh baskets that are filled with rocks or other hard material. They have been used to build instream structures such as weirs and wing deflectors. After several years, the wire mesh typically deteriorates due to abrasion, leaving broken and protruding wire from the disintegrating baskets. This creates a hazard to fish and humans. DFG recommends that gabions never be used within the flood prone area. Gabions can be useful as buried dead man anchors.

Gabion wire baskets are formed using the wire ties provided with the gabions. The empty gabions are firmly anchored and filled with rock. It is best to use angular, durable, un-fractured rock with a flat side facing the exterior of the gabion. When more than one gabion is used, secure the gabions together with heavy wire.

Logs

Logs can be used individually, or in combination with other logs, root wads, or boulders. Longevity is highly dependent on the tree species and percentage of time that the log is saturated. Redwood, western red cedar, Port Orford cedar, and Douglas fir can be expected to last the longest. Spruce, hemlock, white fir, pine, and hardwoods are least durable. The longevity of most logs can also be increased by removing their bark. Logs are buoyant and will float if not secured or weighted down adequately.

Logs can be used for a variety of applications: weirs, wing-deflectors, digger logs, cover structures, cribbing, and bank armor. Full-channel log structures are susceptible to washout or destabilization during periods of high stream flow if not adequately secured.

Root Wads

A root wad with an extensive root network can provide complex fish habitat throughout the year depending on where it is placed. Root wads can be anchored in a variety of locations including mid-channel, at the stream margins, or in pools, to enhance summer and winter habitat. Root wads with a long section of log intact are most valuable since they are easier to secure in place. Root wads must be well secured, preferably to bedrock, boulders, or stable logs.

Boulders

Competent boulders can be used in a variety of applications. They are especially suited for instream structures including weirs, wing-deflectors, and boulder clusters. Boulders are used extensively as riprap to stabilize failing stream banks. Logs, root wads, and boulders are often used in combination to form cover structures.

Boulders are among the most aesthetically pleasing of all stream enhancement structural materials. It is often difficult to tell whether their presence or arrangement is natural, or the product of habitat improvement efforts. Stream size does not limit their suitability. In wide stream channels, boulder weirs are more stable than log weirs because of the tendency for logs to float and disassemble.

The ideal situation is to locate a source of boulders close to the work site. The boulders must be of appropriate size, only use boulders that are as large or larger than those already in the stream channel. They must also be available in adequate quantity, and be un-fractured so they will withstand rough treatment during loading, unloading, and placement. Highly durable boulders are essential if cable and polyester resin adhesive are used to secure the boulders.

Angular quarry boulders are more stable under high stream flow conditions than round stream boulders. Burying approximately one-third of a rounded boulder into the substrate can help compensate for this drawback. Boulders should not be taken from the streambed if their removal decreases existing suitable habitat.

Boulder weights can be estimated by the size of the boulder. The following table estimates the weight of a boulder as approximately 150 pounds per cubic foot.

Diameter (feet)	Volume (cubic feet)	Weight (lbs)
2.0	4.2	627
2.5	8.2	1224
3.0	14.1	2115
3.5	22.4	3359
4.0	33.4	5014
4.5	47.6	7139
5.0	65.3	9793

Heavy equipment is usually required for transporting and positioning boulders. If access to the project site is unsuitable for a dump truck, cost per boulder will increase because of the additional time necessary for a front end loader or bulldozer to deliver individual boulders. Under some circumstances it may be most cost effective to transport and place boulders by helicopter.

At remote sites, boulders may be moved a short distance with hand tools such as a griphoist. An effective method for preparing to move a boulder is to drill a hole in the boulder and secure a short section of cable to the boulder using polyester resin adhesive (Figure VII-3). The griphoist cable is secured to the cable in the boulder with cable clamps. In some cases, chokers or rock nets are also used to move boulders. Griphoists must be secured to an anchor that is either found or created and should be in-line with the boulder and the final desired location. If anchoring to a live tree, measures must be taken to protect the tree. An anchor can be made by drilling a hole in bedrock or in a large boulder and securing a section of cable with polyester resin adhesive.

An effective technique is for one person to operate the griphoist while a second person works behind the boulder with a pinch bar to help guide the boulder and to prevent binding. Snatch blocks can be used to increase the pulling capacity of the griphoist, or to change the angle of pull. A griphoist is equally effective in moving large logs.

Miscellaneous Structural Materials

Geotextile fabric and woven-wire fencing material are often used together on log bank stabilization structures before back-filling with cobble and boulders. The material serves to retain bedload or fill material and help establish and maintain the integrity of the habitat structure.

Geotextile Fabric

Geotextile fabric is available in a variety of textural weaves, strengths, and pore sizes. It is not easily punctured or torn and is available in UV-resistant form for applications where it may be exposed to sunlight. Regardless of pore size, it appears that accumulations of fine sediment and sand eventually prevent movement of water through it. It can also be used effectively as a silt trap during construction of instream structures.

Wire Fencing

High quality wire fencing is woven rather than welded and must be galvanized to ensure longevity. Some types of fencing are PVC-coated and generally have excellent longevity, especially if covered with rock.

Geotextile fabric and wire fencing are often used together on log bank stabilization structures. The geotextile fabric prevents the fine sediment from flowing under the logs and the wire fencing adds structural stability. When using wire fence to add structural stability to a log bank stabilization structure, care must be taken to ensure the wire is properly anchored down and back-filled.

It was once common practice to install geotextile fabric and wire fencing on the upstream side of log channel-spanning structures to prevent water from flowing under the log. This practice has been discontinued. Often, the fabric and wire are lifted over the log structure by the hydraulic force of the water. This can result in the wire posing a potential hazard to people and fish.

Concrete

Concrete is a building material made by mixing cement, sand and gravel with water. Concrete is used to build walls and floors in projects such as fishways and culverts. Concrete cures under water. However, care must be taken to prevent concrete from leaking into the stream, since it is toxic to fish (pH shock) until set and cured. Broken concrete has been used in some areas as riprap. This is not recommended, since its density and resistance to scour are less than that of most rock and it usually does not stay in place or last long.

Wire Rope

Wire rope or cable comes in a variety of diameters and types. Stainless steel cable has the longest life, but is very expensive. Galvanized wire rope is coated with zinc to improve rust resistance. It is relatively free of grease coating, making it suitable for polyester resin adhesive applications. Its longevity is probably greater than non-galvanized steel wire rope. Non-galvanized steel wire rope is lubricated to alleviate abrasion between wire strands when the cable is in motion and under stress. The grease also helps to retard rusting.

There are several ways to cut wire rope in the field. Guillotine type cable cutters are commonly used. These work well but tend to fray the end of the cable making it difficult to push the end of the cable into a hole drilled in a boulder or bedrock using polyester resin adhesive. A skill saw equipped with a metal cutting blade makes a clean cut of the cable, leaving no frayed ends.

ANCHORING TECHNIQUES

The failure of an anchor is probable unless the structure is properly constructed following these recommended techniques. Steel rebar, wire rope, and expansion bolts are the most commonly used materials for anchoring systems. All have several varied applications. Trenching and the use of a deadman are techniques used to stabilize and hold structures in place.

Cabling to Boulders or Bedrock Using Polyester Resin Adhesive

When dealing with durable, un-fractured boulders or bedrock, the cable and polyester resin adhesive technique is a cost effective method of anchoring stream enhancement structures (Figure VII-3). The technique can be used to secure boulders in sequence, or to secure logs or root wads to boulders or bedrock. This anchoring technique can be accomplished using rock drills capable of drilling holes up to one inch in diameter, at a variety of angles.

Before using polyester resin adhesives, read and follow all manufacturer's labels concerning use of this product. Polyester resin adhesives can be used in wet or dry conditions. The hole diameter drilled must be no more than one-eighth inch larger than the cable to be used and should be approximately 10 inches deep. Clean the hole using water or air and a brush to remove all debris. All the rock dust must be removed from the hole or the polyester resin adhesive will adhere to the dust and not to the rock. Use clear, clean water to thoroughly clean drilled holes and ensure the polyester resin adhesive will adhere to the rock, not the dust or silt. Cut the cable to the proper length, keeping cable slack to a minimum between the fastening points. Clean the cable using acetone or muriatic acid. Galvanized wire rope is relatively free of grease and requires much less cleaning than lubricated wire rope. The cable must be absolutely free of oil to get a good bond with the polyester resin adhesive. It is important when using acetone or muriatic acid that precautions are taken to protect the person doing the cleaning, and that it is accomplished away from the stream in case of an accidental spill. Fill the hole approximately two-thirds full with polyester resin adhesive. Insert the cable, turning slowly when possible, until the cable hits the bottom of the hole. Air pockets left at the bottom of the hole reduces bonding strength. Polyester resin adhesive must be used prior to the indicated expiration date.

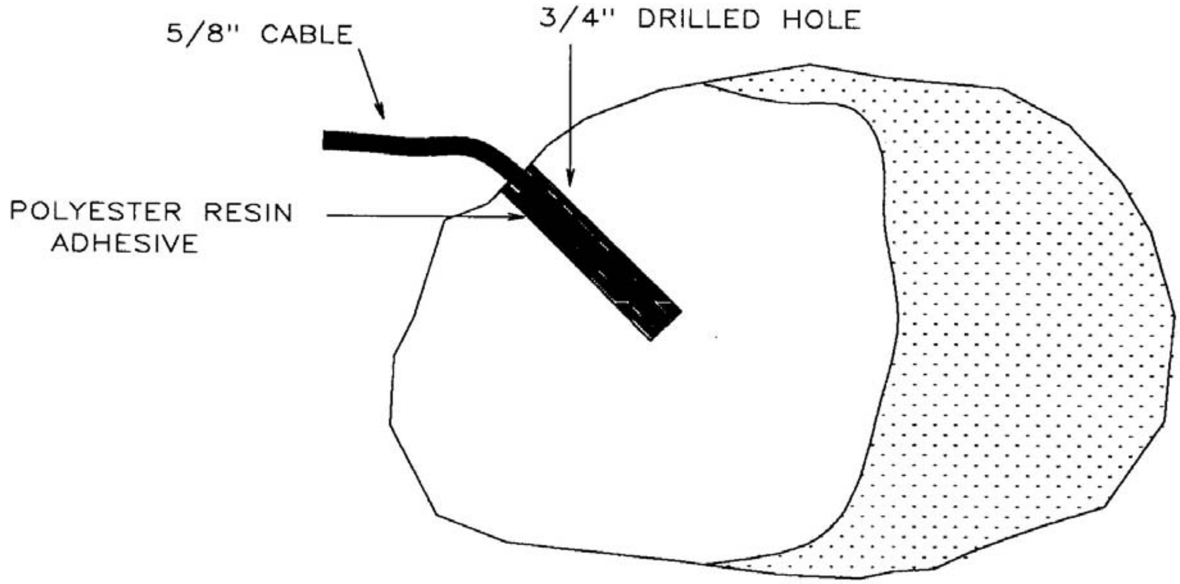


Figure VII-3. Cable secured to boulder using polyester resin adhesive.

Cabling to Logs and Root Wads

Woody material should be secured by inserting the cable through the log or root wad. Where this is not possible, notching the material to recess the cable is necessary. Always remove bark at the point of contact between the cable and the log or root wad because bark will rot, resulting in slack in the anchoring cable. When threading cable through augured holes, or wrapping it around logs or root wads, cable clamps should be used to fasten the cable. A minimum of two clamps is required to prevent slippage. The cable should be looped through the hole, and around the material and clamped back to itself. Simply placing a clamp on the end of the cable will not suffice because it can be pulled off, or pulled through (Figure VII-4).

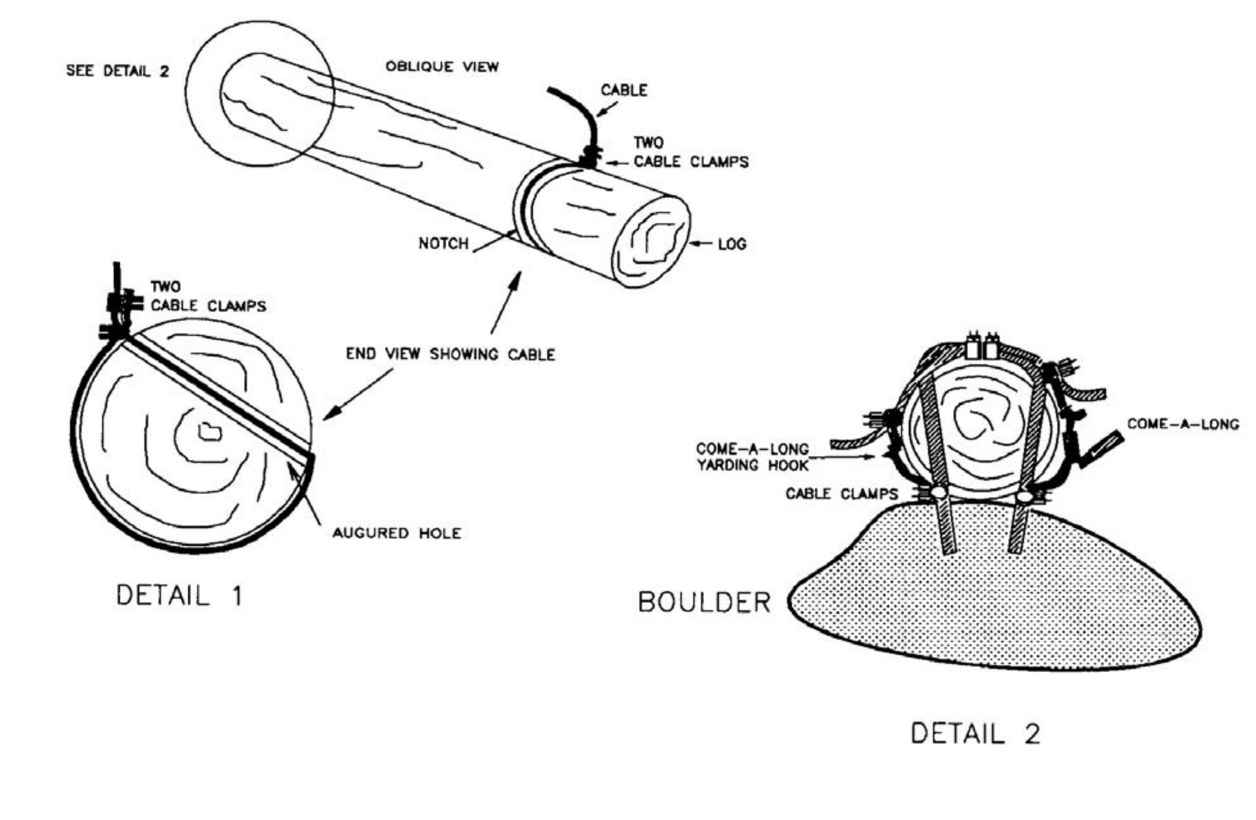


Figure VII-4. Cabling to log.

Cabling Logs and/or Root Wads to Boulders or Bedrock

Logs or root wads to be secured instream must be anchored tightly so they do not float or move. A procedure has been developed called the "two-cable method" for anchoring logs to boulders or bedrock. Two griphoists are used to pull the cables tight using this method. Commercially available cable grips, or a special tool called a cable-hook clamp can be used to facilitate tightening of cables with a griphoist.

To construct a cable-hook clamp, saw off the eye of a slip hook and weld it to a cable clamp base. Use a cable clamp one size smaller than the cable to be used (example 1/2-inch cable clamp for 5/8-inch cable). It may also be necessary to use welding rod to build up mounds in the cable cradle to aid in holding the cable ends (Figure VII-5).

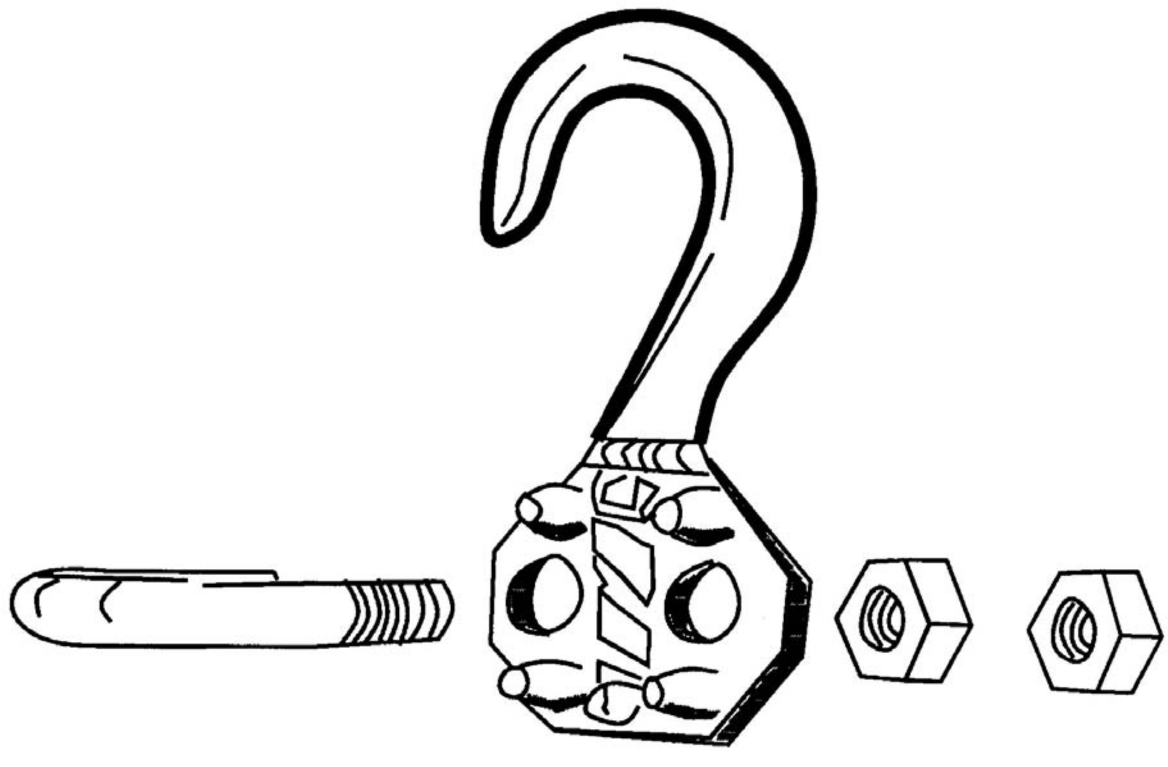


Figure VII-5. Cable hook clamp.

To cable a log to a boulder or bedrock using the two-cable method, drill two holes to a minimum depth of 10 inches. The angle of the holes should match the direction the cable will be pulled to prevent excessive bending at the rock face. The layout of the griphoist anchors must be arranged to set up opposing pulls in alignment with the log structure to be secured. Follow directions for use of the cable and polyester resin adhesive. Allow the adhesive to set up overnight. Drill holes for the cable through the log. Using the hook clamps, attach cable ends to the griphoist (Figure VII-6). Loosely attach a minimum of two cable clamps to the cables before tightening the cables with the griphoist. Pull both cable ends with the griphoist, avoiding binding as the cables move past each other. When cables are at maximum tension, tighten the cable clamps. Remove griphoists. Check cable tension. If cables are not tight, loosen the cable clamps and repeat the process. Secure the loose cable ends to the log with staples (Figure VII-7). Two variations of the two-cable method are shown in (Figures VII-8 and VII-9).

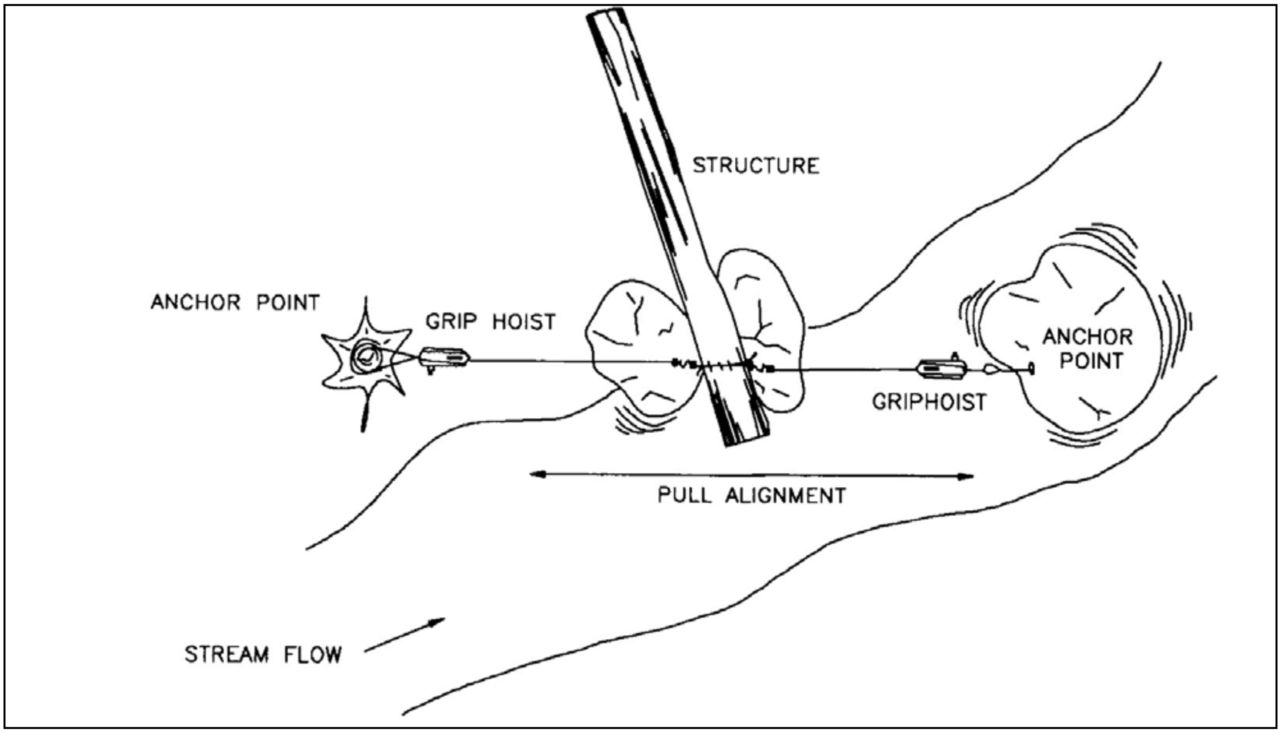


Figure VII-6. Tightening cable ends using two griphoists.

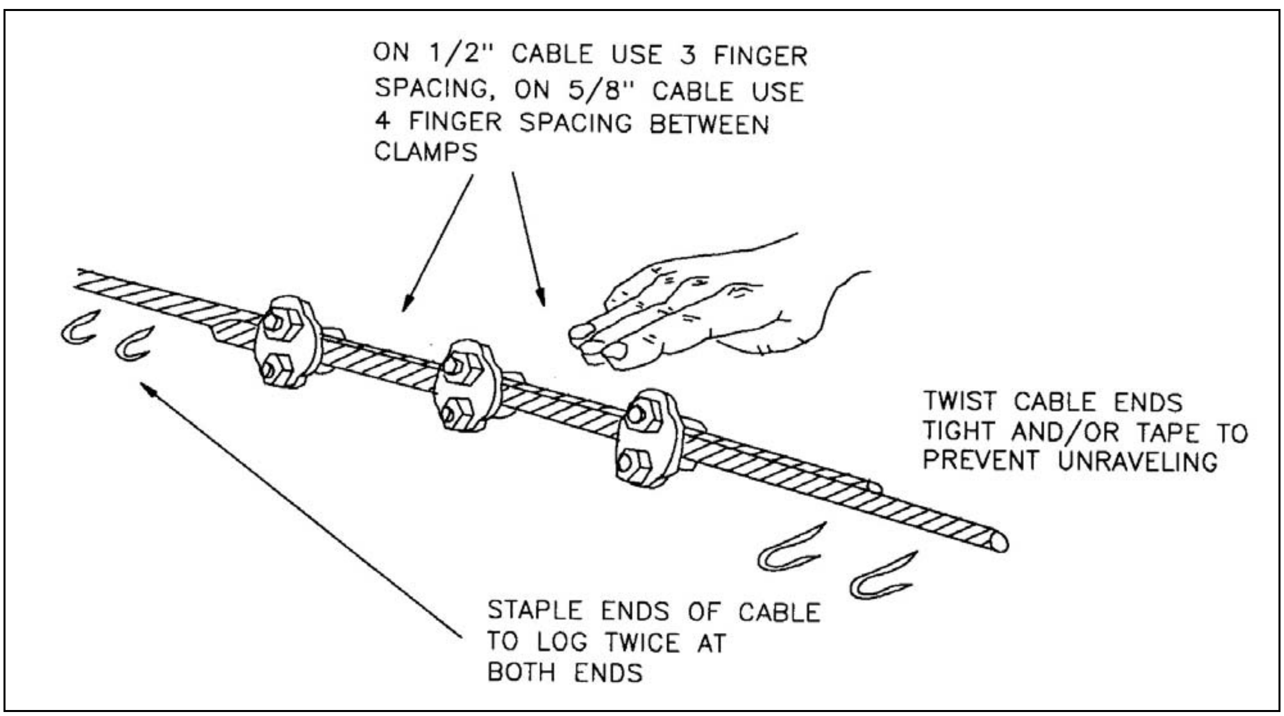


Figure VII-7. Attach cable clamps to cables.

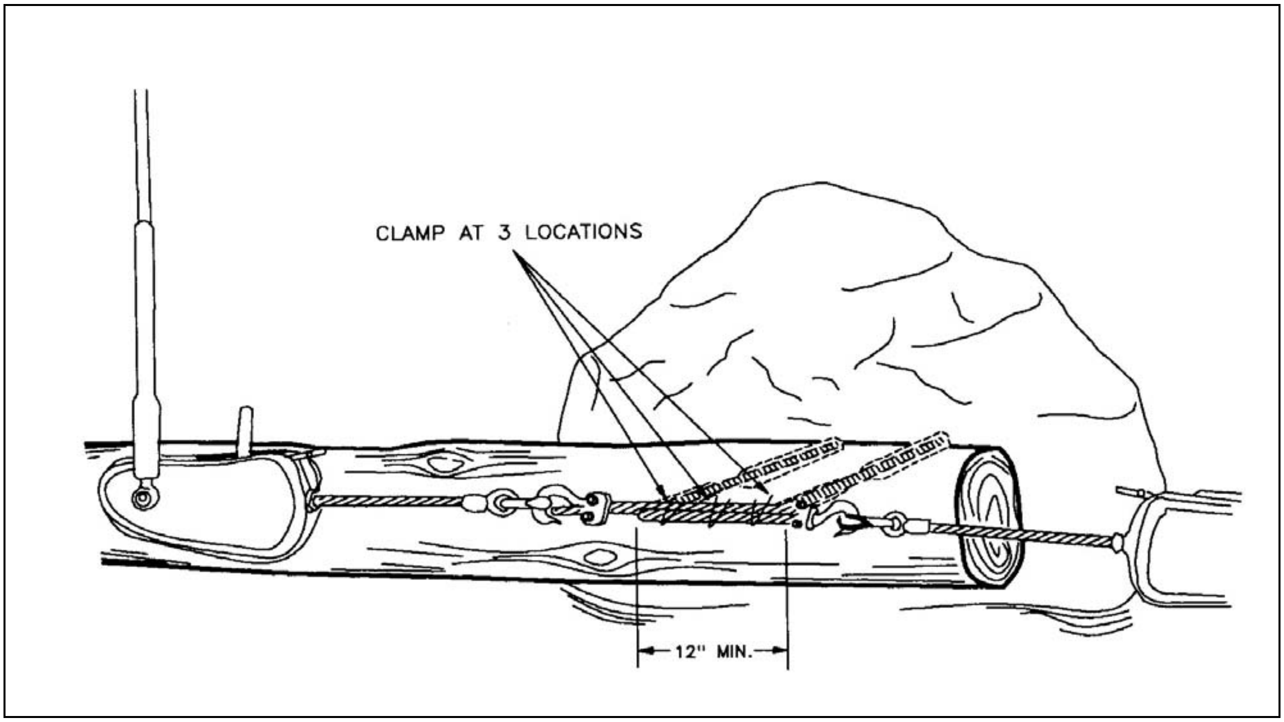


Figure VII-8. A variation of the two-cable method.

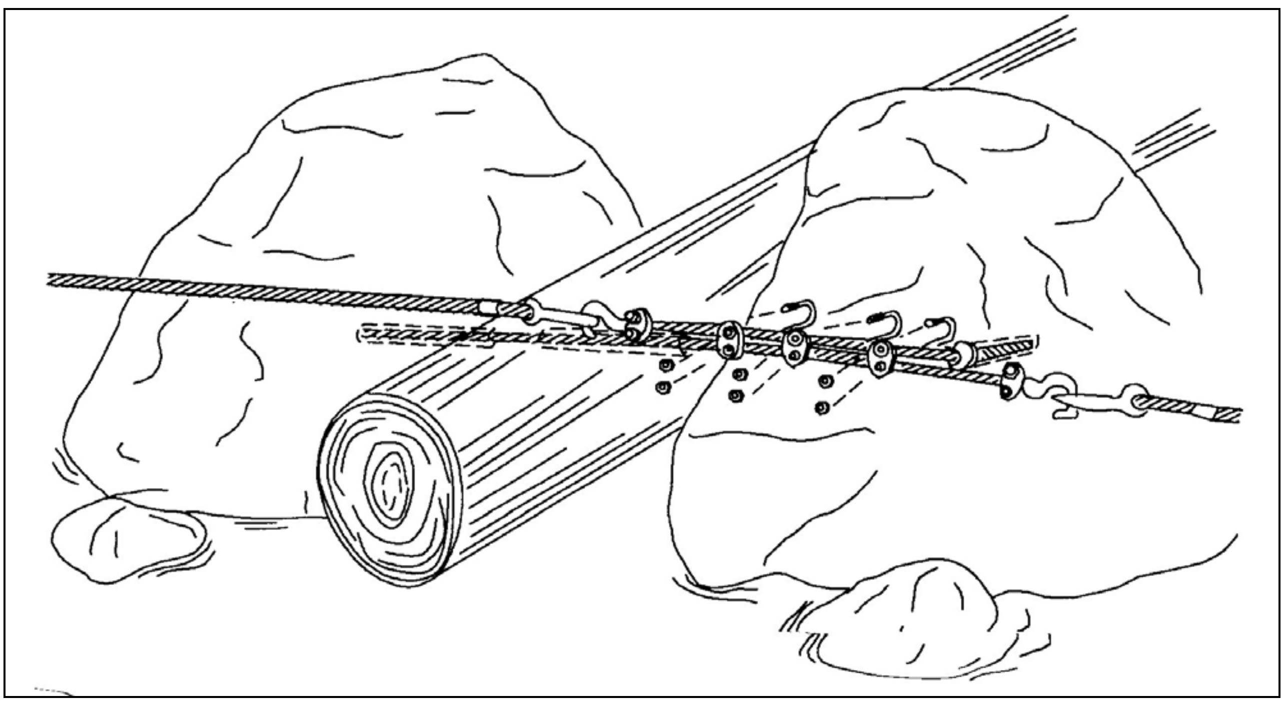


Figure VII-9. A variation of the two-cable method.

Log Pinning With Rebar

In addition to being a component of reinforced concrete, rebar can also be used in anchoring applications. To pin logs together with threaded rebar, an aligned hole is augered through both logs. A length of threaded rebar is inserted through the holes, a steel-plate washer and nut are then placed on both ends of the rebar and tightened to secure the logs. Before driving in threaded rebar, a nut must be threaded on the impact end of the rebar to protect the threads from being damaged (Figure VII-10). After the nut has been tightened, the end of the threaded rebar must be mushroomed to prevent the nuts from backing off. Minimum recommended size of threaded rebar is one-inch. The minimum size steel-plate washer recommended is three-inches square, by one-quarter inch thick.

If standard non-threaded rebar is used, a pilot hole slightly smaller than the diameter of the rebar should be drilled through the log(s). The rebar is then driven in far as possible using a metal fence post driver, then a sledge hammer is used to drive it the rest of the way. It is important to bend over the ends on the rebar at least at a right angle so logs will not lift off.

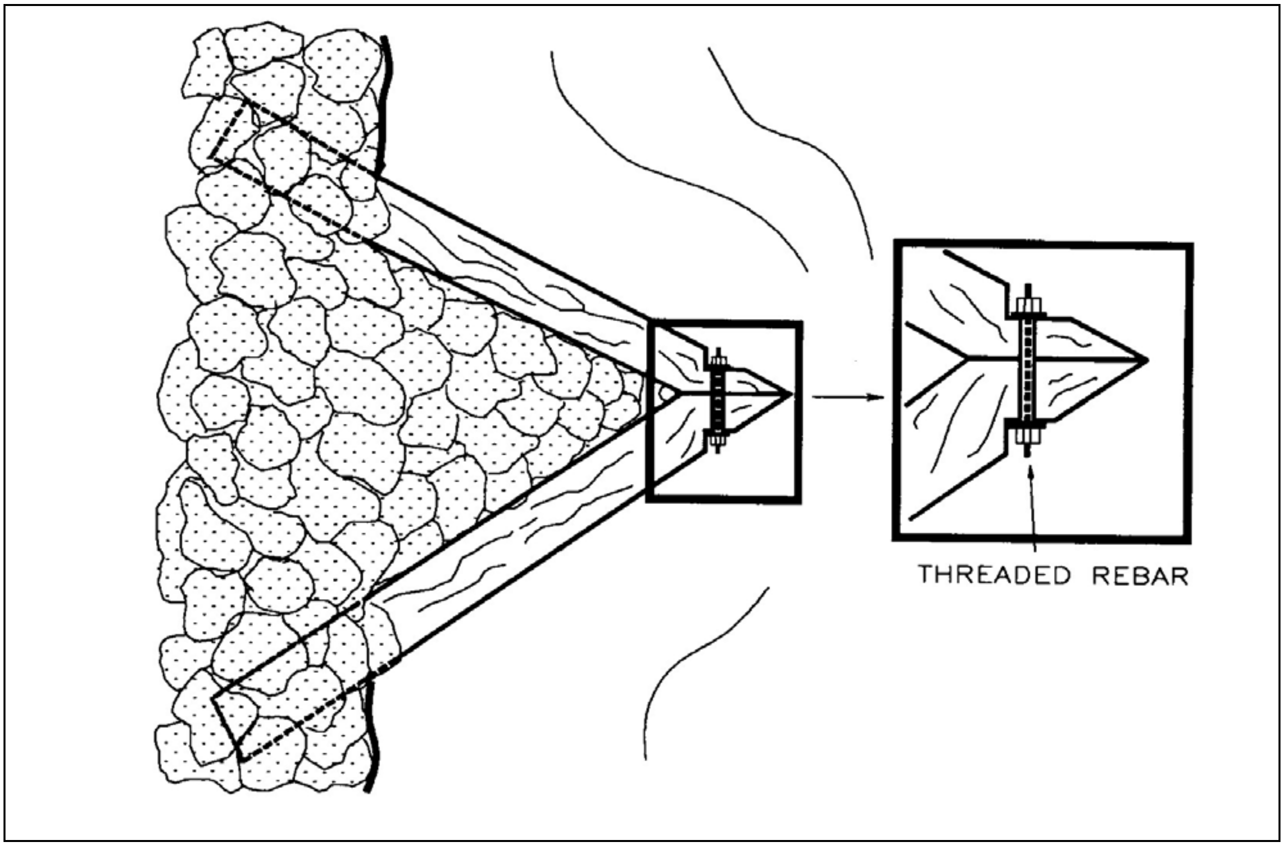


Figure VII-10. Threaded rebar used to secure two logs together.

Stream Bank Anchors Using Rebar

Steel rebar can be driven into the stream bank to hold log structures in place. This technique is only to be used in conjunction with additional anchoring techniques such as a deadman, cable secured with polyester resin adhesive to a boulder or bedrock, or with threaded rebar to a stable or embedded log (Figure VII-11). Logs are very buoyant and will float away if not securely anchored.

A post driver or sledge hammer are best suited to driving rebar. Rebar anchors must be at least 10 feet in length, to ensure that they are not uncovered by high stream flows. The rebar can be trimmed to create a point. The pointed end will help penetrate hard ground or buried woody debris. If scour is expected at the end of a structure, the ends should be anchored by other means.

Often, rebar cannot be driven into a heavily armored stream bank. It frequently bends at cobble and boulder obstructions, or reaches impenetrable bedrock. However, an increased number of rebar anchors may be able to compensate for shallow penetration.

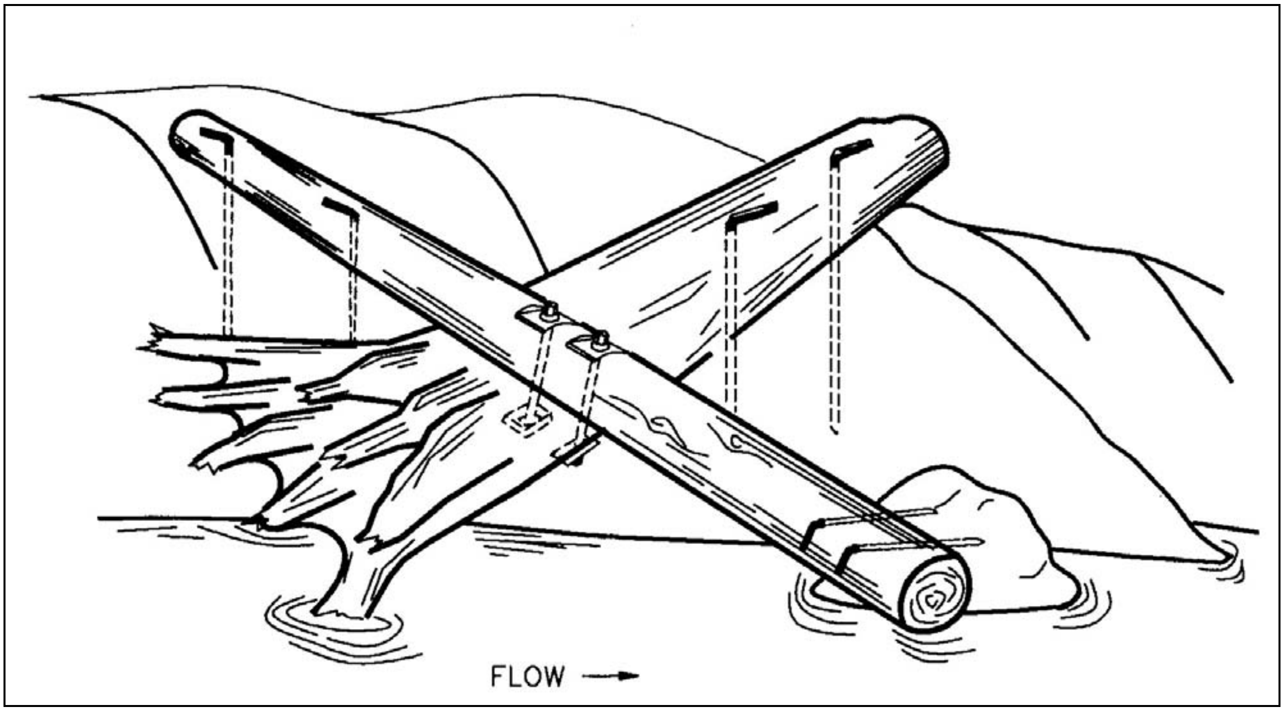


Figure VII-11. Rebar anchoring application.

Bedrock and Boulder Anchors Using Threaded Rebar

Threaded rebar can be secured to bedrock using polyester resin adhesive (Figure VII-12). Hole depth must be sufficient to reach competent, un-fractured rock in order to obtain maximum bonding strength. A minimum of 10 inches is recommended. Setting rebar into fractured rock or into a hole that has not been cleansed of rock dust may not produce a reliable bond.

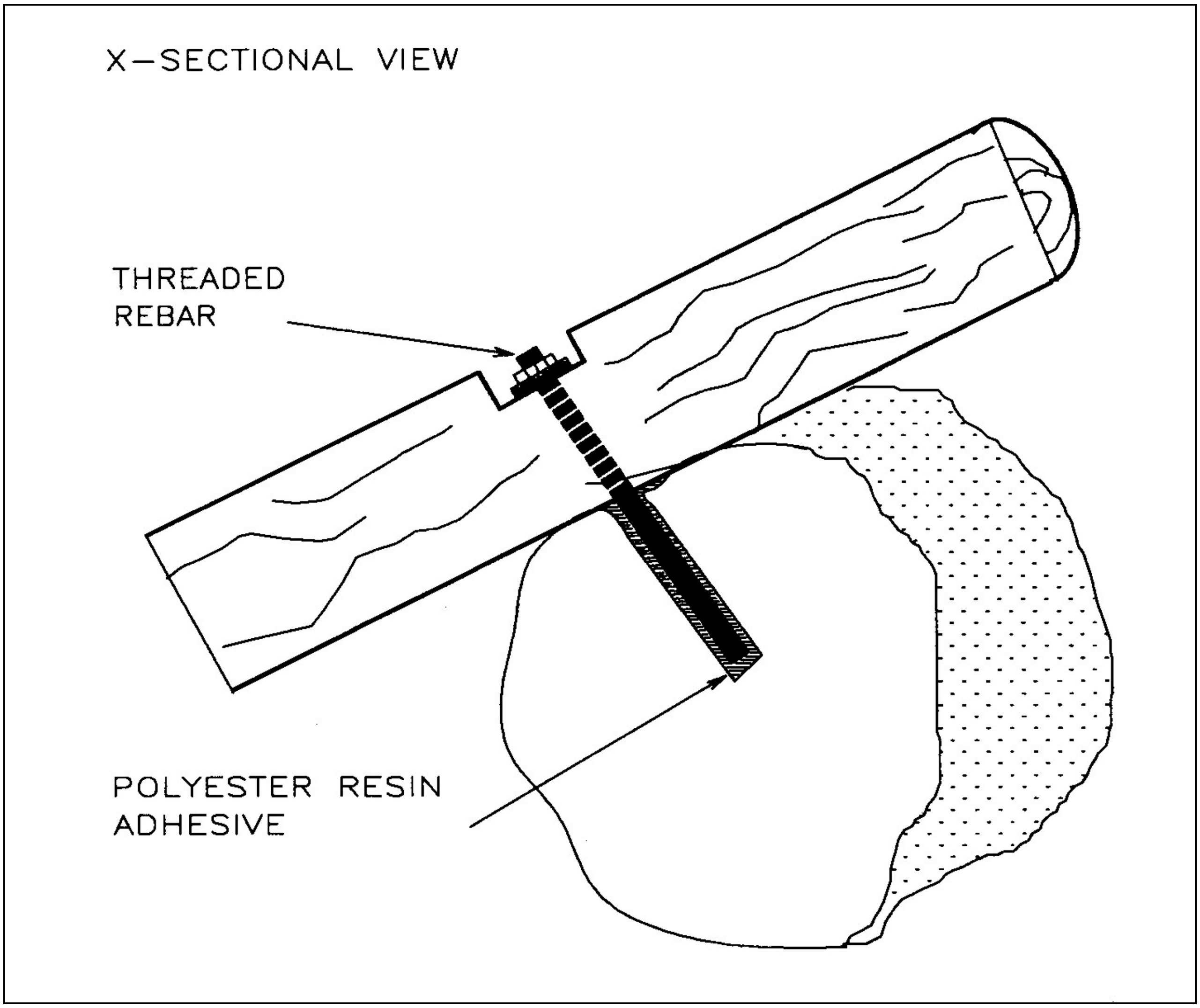


Figure VII-12. Threaded rebar anchoring log to boulder, using polyester resin adhesive.

Threaded Rebar and Cable Anchor to Boulder or Bedrock

North Coast Fisheries has developed an anchoring technique using threaded rebar, cable and polyester resin adhesive to secure logs or root wads to boulder or bedrock. The log is moved into position. Holes are drilled into the boulder or bedrock after the log is in-place. The cable is secured to the bedrock or boulder using polyester resin adhesive. The adhesive is allowed to cure overnight. A hole is drilled through the log in line with the cables. The bark and cambium layer of the log are removed so the plate will fit against the heartwood of the log. Threaded rebar is driven through the hole leaving three to four inches of rebar sticking out on each side. A loop is formed on the end of the cable using two cable clamps. The loop is tightly threaded over the rebar leaving as little slack as possible. The cable clamps used to form the loop in the cable are tightened down. The metal plate and nut are threaded on the rebar and tightened down (Figure VII-13).

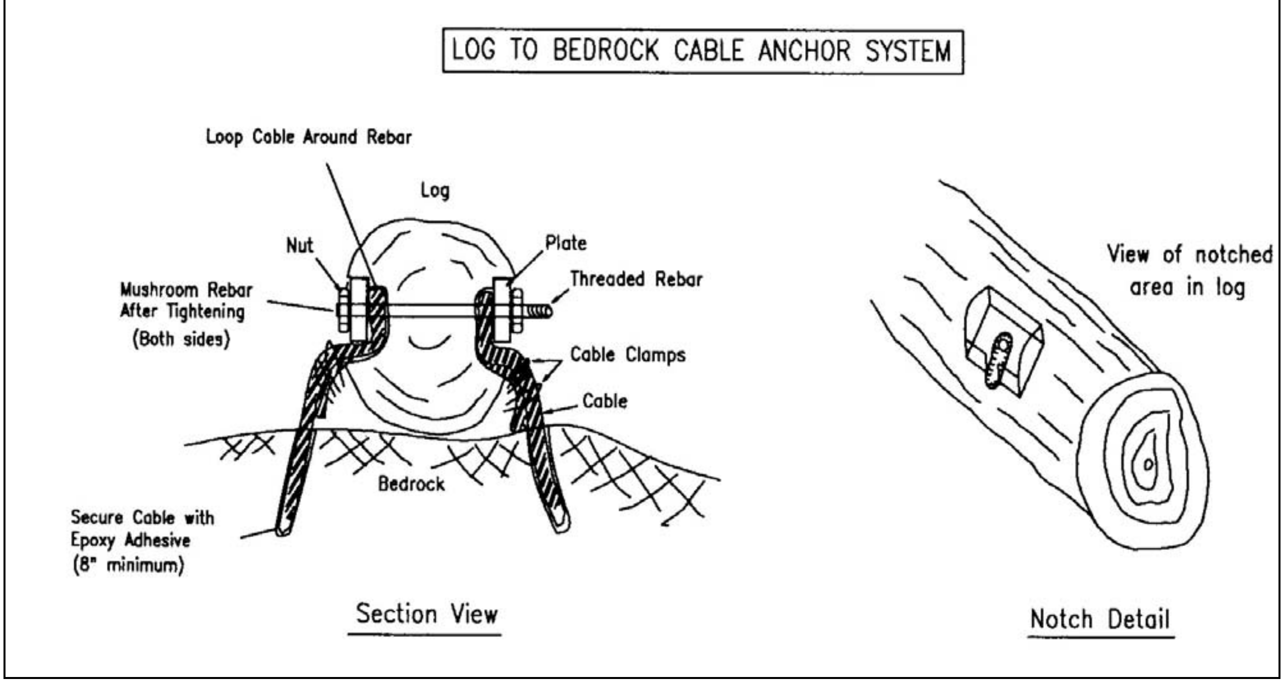


Figure VII-13. Threaded rebar and cable anchor to boulder or bedrock.

Expansion Bolts

Steel expansion bolts provide a means for establishing an anchor point in concrete. This method is commonly used when anchoring steel Washington baffles in concrete box culverts. There are a wide variety of commercially available anchors suitable for fish habitat construction purposes. Typically, a series of ridges on drop-in anchors are embedded in the sides of a drilled hole as the anchor is expanded by insertion of a threaded bolt; or a clip is expanded and wedged into the sides of a hole when a nut is tightened to compress it against the opposite end of the bolt (Figure VII-14).

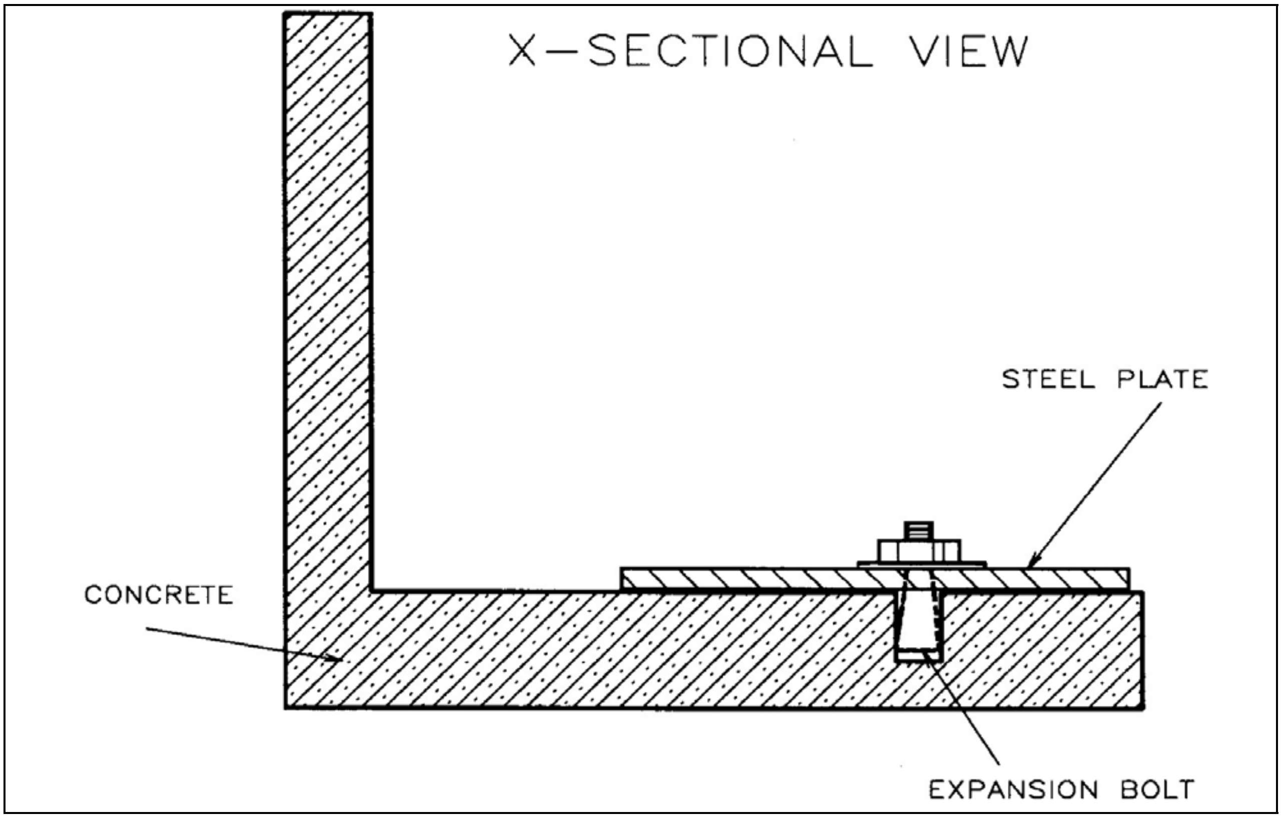


Figure VII-14. Expansion bolt into concrete.

Trenching

Trenching is an anchoring technique that is used to "key-in" or recess structures. Recessing a log or boulder into trenches excavated in the substrate or the bank reduces the chances of high stream flows undermining the structure or cutting around the structure's ends. Trenching stream banks to key in structures can only be accomplished where suitable, stable banks are present. Trenching can be performed either with heavy equipment or by hand (Figure VII-15).

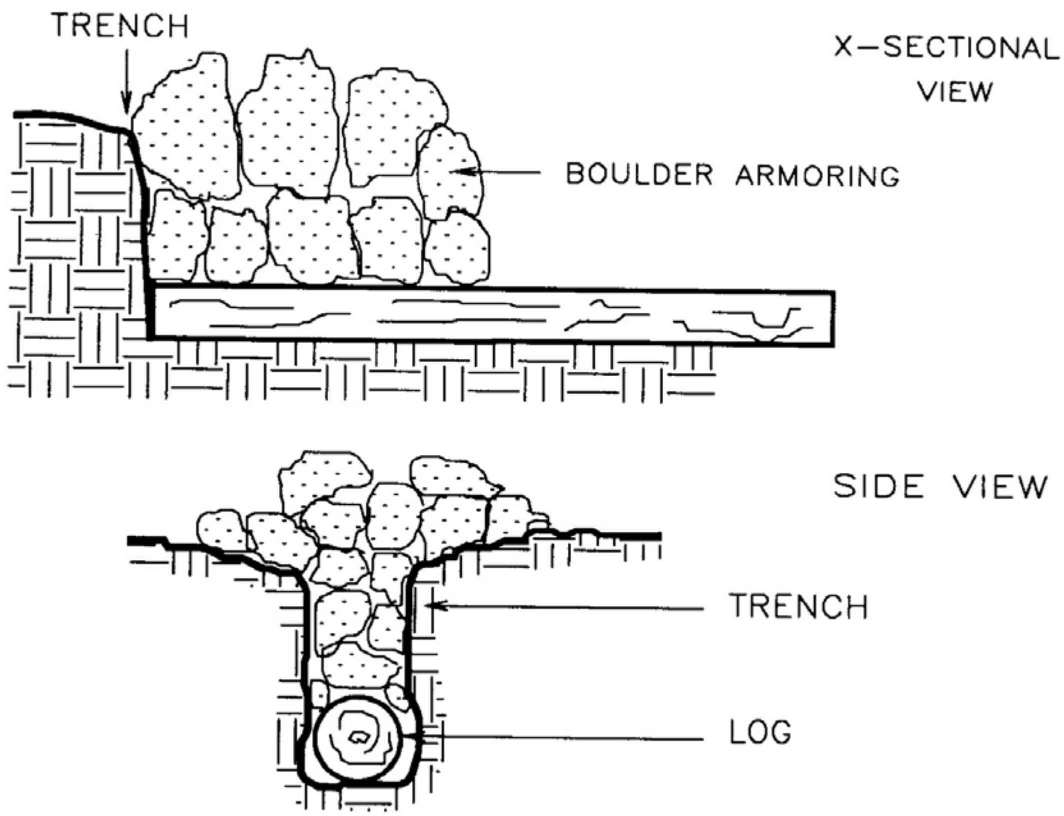


Figure VII-15. Trenching.

Deadman

Where no natural anchors, such as trees, stumps, or boulders are present, an anchor point must be constructed. This is possible using a "deadman". A log, boulder, gabion, or other structurally sound object can serve as a deadman. The deadman is buried in the stream bank, and becomes a stable substrate fixture.

The deadman must be buried at least 3-feet deep on the stream bank above bankfull flow. The deadman, with several attached anchoring cables, is placed in the pit. The cables extending from the deadman are placed in narrow trenches dug down to the instream structure. After attaching the cables to the habitat structure, the cables are tightened, and the pit and trenches are back-filled and compacted (Figure VII-16).

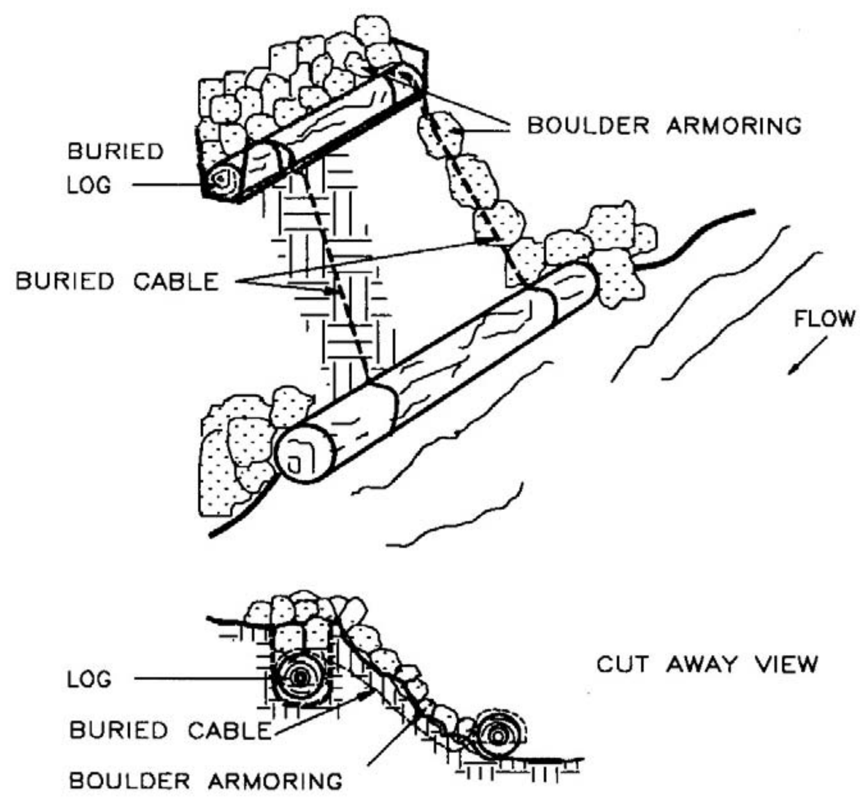


Figure VII-16. Deadman.

Unanchored Large Woody Debris

Most instream habitat enhancement structures require some type of anchoring technique to ensure they will remain in place during high flow events and to prevent high flows from altering their configuration and intended function. However, in particular cases the addition of unanchored large woody material may be beneficially used to enhance some streams and stream reaches. In small streams, large woody debris (LWD) is often the structural agent in pool formation or a key element associated with the habitat quality of a pool. The effect LWD has on channel morphology is influenced by its size, orientation, spacing, and association with other structural elements as well as a number of other variables including stream-flow energy, sinuosity, substrate, bank composition, and channel width. First through third order streams are generally best suited for unanchored LWD placement projects. Where appropriate, the placement of unanchored LWD requires no maintenance and are free to adjust naturally to the stream=s hydraulic regime.

In unanchored applications, logs selected for placement should have a minimum diameter of twelve inches and a minimum length 1.5 times the mean bankfull width of the stream channel type reach and the deployment site. A root wad should be selected with care and have a minimum root bole diameter of five feet and a minimum length of fifteen feet and at least half the channel type bankfull width. Regardless, a DFG Fish Habitat Specialist must be consulted prior to initiating these projects and obtaining necessary DFG permits.

INSTREAM HABITAT IMPROVEMENTS

There are three general categories of the most commonly used instream structures: 1) cover structures; 2) boulder structures; and 3) log structures. Often a single structure or combination of structures will provide for rearing, spawning, and cover. It is important that instream structures be monitored after high flows have occurred to determine if the desired habitat condition has been met (Part VIII, Project Monitoring and Evaluation). Often, maintenance or modification is needed to make the structure perform properly.

Cover Structures

Quality of a pool can be increased by adding cover structures. Amount of effective cover and the complexity of habitat is at least as important as the physical amount of pool created. Strategically placed cover can help keep pools scoured, while improperly placed cover will cause deposition of sediment.

A study on the effectiveness of placing tree bundles of fir, alder, maple, and myrtlewood was conducted on five different Oregon streams. Juvenile coho and steelhead populations were sampled in 16 pools before and after tree bundles were added. Before the tree bundles were added the pools sampled were holding 12 percent of their summer coho population during the winter. The following year, after tree bundles were added, these same pools contained 74 percent of their summer coho population during the winter sampling. The sampling showed an increase in steelhead populations between the summer and winter populations, the winter after tree bundles were added.

Riparian vegetation is a highly important source of cover. Overhanging vegetation or undercut banks, along with the associated roots, provide excellent, effective cover.

Logs, root wads, tree bundles, and boulders are the primary cover elements added to pools. Some guidelines concerning construction and installation of cover structures in a stream are:

- Cover should be incorporated with other stream enhancement structures such as log and boulder weirs, boulder clusters, and single and opposing wing-deflectors.

- Cover structures are often placed in pools, backwater areas, or along meanders to provide protection.

- Logs, tree bundles, or root wads can be cabled against the banks. Secure logs or root wads to a stump, a live tree, a bedrock outcropping, large boulders, or use a deadman. Cover can also be cabled to instream boulders using polyester resin adhesive.

- Cable all log and root wad cover structures tightly.

- Protect the upstream end of logs from direct flow of the stream.

Examples of cover structures are divide logs; digger logs; spider logs; and log, root wad and boulder combinations.

Divide Logs

Divide logs are installed mid-channel in spawning riffles to provide a visual barrier between adjacent spawning areas. This can increase spawner use of a riffle area and provide escape cover (Figure VII-17).

Divide logs require suitable substrate for anchoring. Such substrate consists of boulders or bedrock. Length and diameter of the log used will be dictated by length of the spawning channel and depth of flow. In general, divide logs should be 18 to 36 inches in diameter.

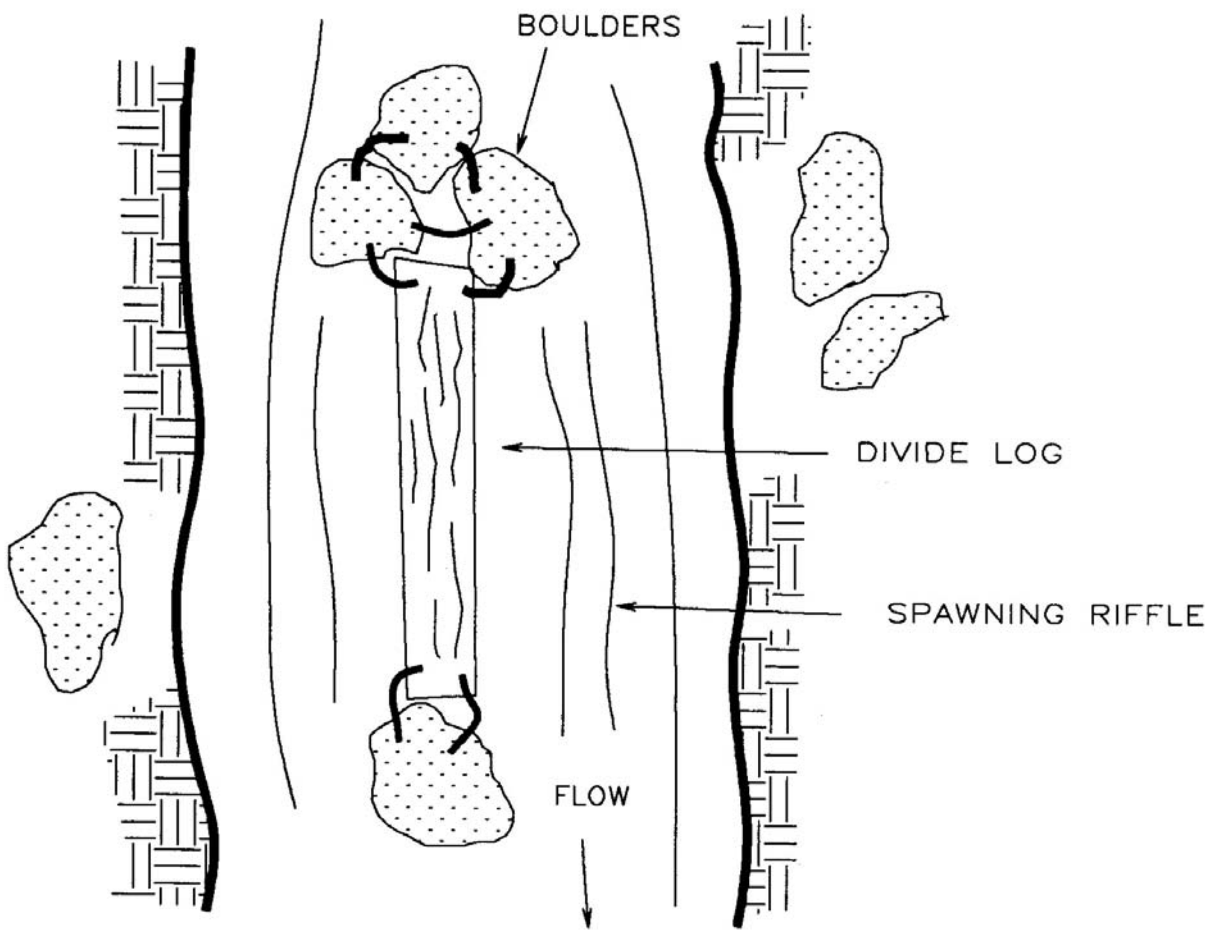


Figure VII-17. Divide log.

Digger Logs

Digger logs are placed with one end anchored securely on the bank and the other end plunging into the bottom of a pool. Primary use of digger logs is to enhance pool habitat by creating diverse cover for rearing juveniles as well as for migrating adults. They are also used to scour the channel, creating or expanding pool habitat. Logs with root wads intact should have the root wad end extending down into the pool to offer the most complexity for increasing rearing habitat and maximizing scour (Figure VII-18). Digger logs will be most secure when two-thirds of the log is on the bank and one-third of the log extends into the channel.

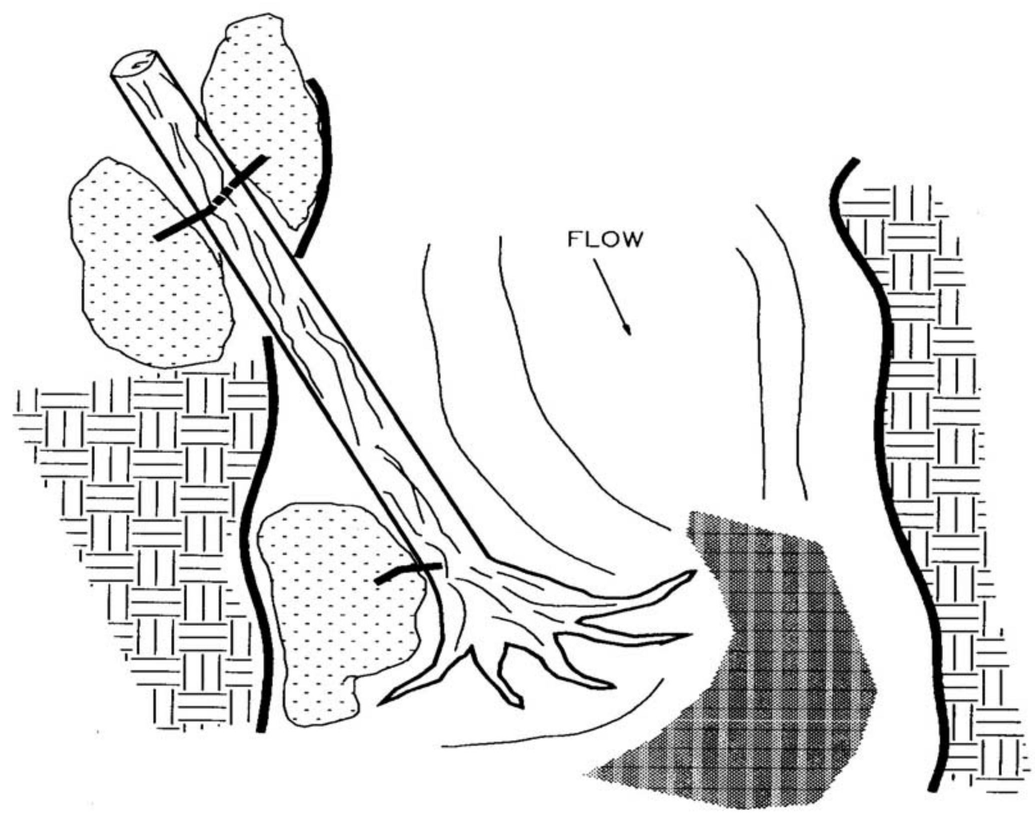


Figure VII-18. Digger log.

Digger logs are usually secured to bedrock and held in place using cable and polyester resin adhesive, or secured to live trees or downed wood with threaded rebar. The log must be anchored in at least two places, with anchors spaced as far apart on the log as possible to keep it secure during high flows. Digger logs can be set in a trench dug into the stream bank. At least one-third of the length of the log should be placed in the bank. This buried end of the log should be covered with boulders to anchor the structure. If the digger log is to successfully create scour, it is important that the end of the log in the water does not float during high flows. Digger logs will usually be positioned to point downstream, although there may be some situations where pointing them upstream would be appropriate (where the intention of the log placement is to create scour). The vertical angle of the log should usually be 30 to 45 degrees to the bank.

Spider Logs

Spider logs, also called mini log jams, are several logs placed at angles to mimic a log or debris jam. They provide cover for juvenile rearing and adult spawning and collect woody debris to increase diversity. Their use is restricted to areas where there is no danger of causing bank failure or channel migration. Pools and backwater eddy areas on the stream channel margins are the best locations for these structures (Figure VII-19).

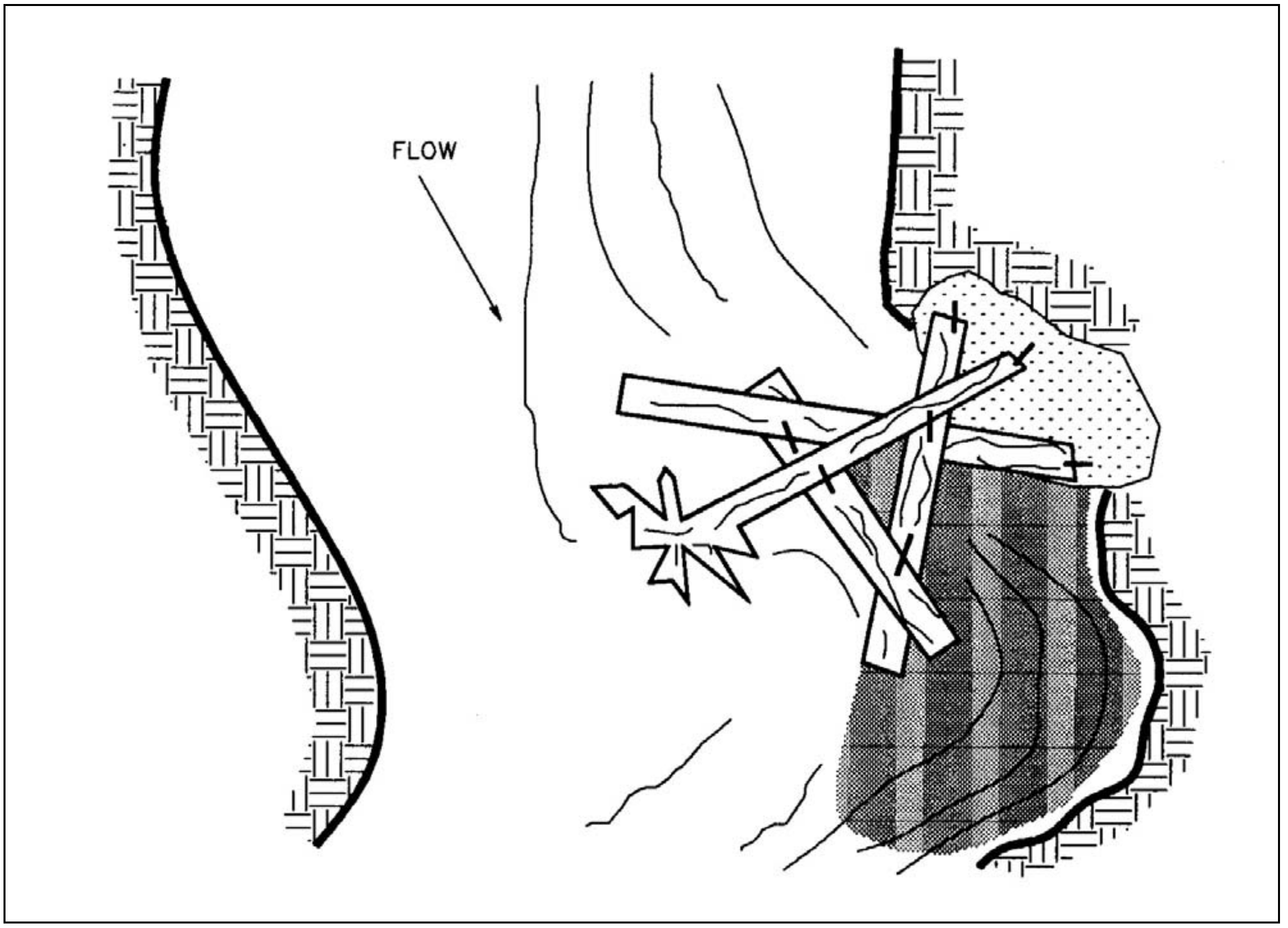


Figure VII-19. Spider logs.

The structures are composed of several logs placed across each other, in the shape of a triangle, to imitate a natural debris or log jam. Each of the logs must be secured to bedrock or large boulders in the channel with cable and polyester resin adhesive, or to live trees with threaded rebar. The logs are secured together with threaded rebar. Several other logs with branches and root wads attached are then fastened to these structure logs with cable or threaded rebar.

Caution must be used in locating these structures as the potential for an adverse effect is great. Before placing spider logs it is necessary to determine channel capacity and bankfull discharge that can be expected. Log structures should not reduce channel capacity below flood stage needs or a massive log jam and sediment trap could develop.

Log, Root Wad, and Boulder Combinations

Log, root wad, and boulder combinations combine the two main forms of structure added to a stream to enhance habitat. The longevity of boulders combined with the cover provided by logs can create habitat that is superior to that offered by either element individually.

Log, root wad, and boulder combinations are used to create cover for juvenile rearing. These structures also act as resting areas and escape cover for spawning salmonids. By creating velocity shear zones they create areas of deposition as well as scour, thereby enhancing spawning through gravel sorting (Figure VII-20).

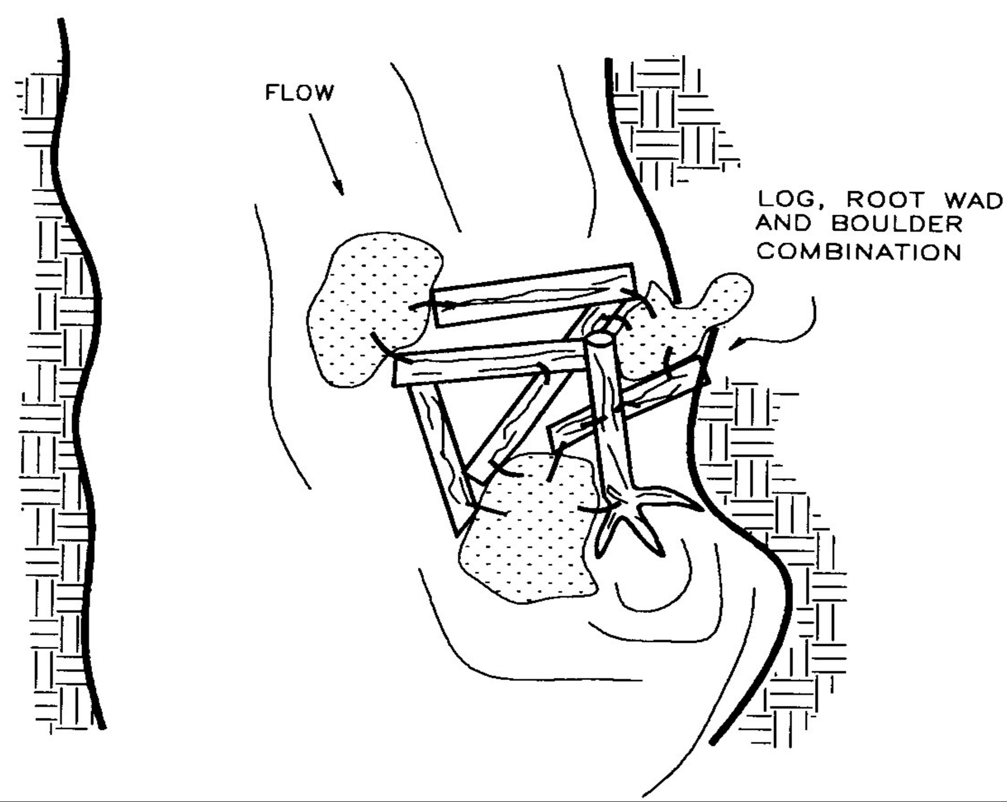


Figure VII-20. Log, root wad, and boulder combination.

Methods used to install log, root wads, boulder combination structures are the same as those used for installing log or boulder structures. The boulders used must be of sufficient size to counteract the buoyancy of the logs. Because of the potential for deflecting high flows into adjacent stream banks, it is important to make sure that banks are resistant to erosion or to take steps to increase their resistance by armoring them with boulders and/or logs.

Boulder Structures

Boulder structures are placed in the active channel and along stream banks for creating a desired habitat type. They are used to break up or diversify stream flow in a particular stream reach, to provide instream cover for juvenile salmonids and spawning adults, or to recruit spawning gravel. It is desirable to create a variety of stream flow velocities, because juvenile salmonids will select different velocities depending on whether they are feeding or resting. Different water velocities will also sort gravel and create diversity in the substrate.

Boulders are well suited for diversifying flows because they are resistant to being displaced by high flows. Because of this they can be placed mid-channel without constructing a full-channel spanning structure. The interstices in boulder clusters and between large boulders can provide escape cover for juvenile and adult salmonids. Boulders must be sized according to stream discharge and channel morphology. Whenever possible, it is best to individually select boulders for use in a project.

There are several disadvantages to using boulders. One is that boulders often must be hauled to the construction site from a quarry. If there is not a quarry nearby, the cost of buying and trucking boulders can be very high. A second problem with using boulders is that if they are placed in mobile substrate, perimeter scour may cause the boulder to bury itself. For this reason, it is necessary to use large boulders, or to secure boulders using polyester resin adhesive and cable to form a larger structure.

Design of boulder structures depends upon the primary function to be served. The range of flows to which a particular structure or series of structures may be subjected will dictate size of boulders to be used, and proper anchoring techniques to be employed.

Boulders can be used in a variety of situations and configurations to perform a desired function or fulfill a particular habitat need. Possible configurations of boulders include weirs, clusters, and single and opposing wing-deflectors.

Boulder Weirs

Boulder weirs are primarily used to collect and retain gravel for spawning habitat, or to create one or more jump pools to facilitate fish passage on marginally accessible or impassable stream reaches. Such fish barriers may be natural or human-induced.

When designing a boulder weir, the following factors must be considered. The boulders used should be larger than boulders occurring naturally in the stream. Large angular boulders are most desirable as they are least likely to roll out of place during high flows. Improper placement of downstream-V and diagonal weirs may direct flow in a manner creating undesirable erosion.

Weirs that span the full channel width can be configured in several shapes including: 1) perpendicular to the flow (if used for back-flooding); 2) diagonal; 3) downstream-oriented "V" (Figure VII-21); and 4) "U"-shaped (if used to improve spawning gravel). General construction principles are the same for all configurations; only one description of construction techniques is presented.

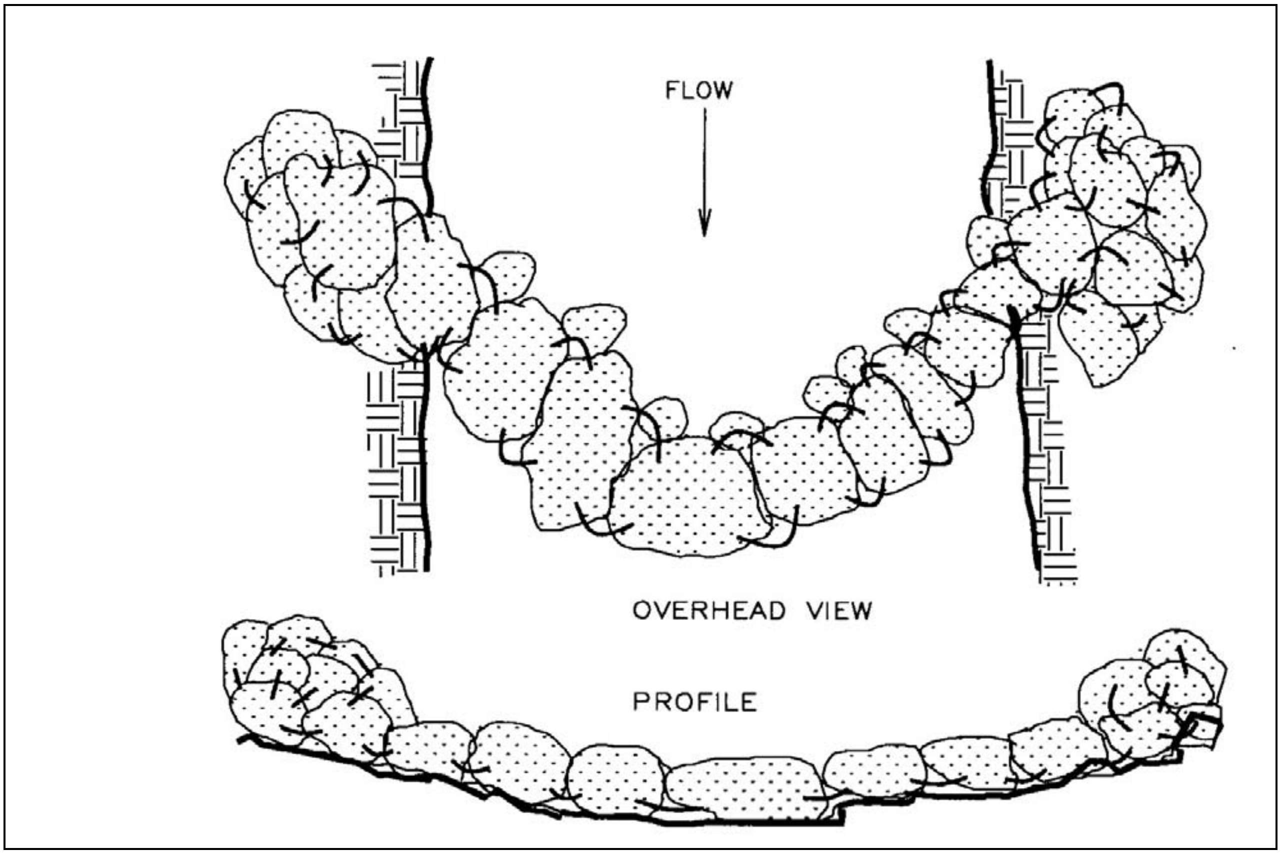


Figure VII-21. Downstream-V boulder weir.

Weirs should be keyed 4 to 6 feet horizontally into stream banks with a gradual downward slope of the weir height toward the thalweg. This slope can be adjusted to position the thalweg. The thalweg will tend to follow the low point in the weir. At the low point of the weir a "spillway" should be constructed by creating an opening one to two feet wide. This creates a notch through which flow is concentrated at low flows. The notch should be roughly triangular in shape with the apex of the triangle oriented down. Flat, broad spillways make fish passage difficult.

The weir should be sealed with smaller rock and cobble to prevent seepage flow and maintain flow over the spillway. This helps to prevent the weir from becoming a low flow barrier to juvenile salmonids.

To assure that the stream is not diverted around the end of the weir during high flows, ends of the weir should be extended to a point above normal high water level. Ends of the weir should be set in a trench dug to a depth of at least one boulder diameter. In bedrock substrate, the boulders on the ends of the weir should be cabled to bedrock. It is important that during high flows the stream does not flow around the end of the weir and cause bank erosion, or establish a new channel.

Quarry boulders will typically be more angular than stream boulders, and depending on the size of the boulders, will be fairly resistant to movement by stream flow. Therefore, they are usually considered to be superior to stream boulders for weir construction. Density of the boulder will also affect its stability in the stream, and how well it stands up to being drilled for cabling. Size of the boulder selected will depend on size available and the magnitude and velocity of stream flow. In general, the bigger the boulder the better. However, the boulder must suit the size of the channel (i.e., a 6-foot diameter boulder would not normally be placed in a 10-foot wide channel, or bank scour is likely).

Oversized boulders are seldom a problem. The opposite is more often the case. If boulders are relatively small and will be subjected to flows of such magnitude that they would not be stable in the stream, they should not be used. Even with suitably sized boulders it is often desirable to secure the boulders together using cable and polyester resin adhesive to create a stable structure. Cabling requires drilling holes into adjacent boulders and securing them with short lengths of cable. It is important that the cables are no longer than the distance between the boulders plus the depth of the holes. Drill the holes in the sides of the boulders (never the top). Any slack or flex in the cable will allow the boulders to move. By cabling adjacent boulders together, a series of boulders effectively creates a single unit which will remain stable during high flows.

Scour created on the downstream side of boulders may create a crater and cause boulders to roll into the scour hole. This is particularly true with stream boulders which tend to be rounded from abrasive action of years of high flows. Cabling boulders together will help reduce the tendency of the boulders to roll. Where possible, boulders should be imbedded into the substrate to a depth one third of their diameter to compensate for their tendency to roll downstream.

A boulder weir can be one or more rows wide. By setting the downstream row or rows of boulders at progressively lower elevations than the one above, a more gradual drop of stream elevation can be created so the energy in the plunge effect of the water flowing over the weir is dispersed over a wider area. Scour will occur slightly farther downstream and won't be as likely to undermine the boulders. Fish passage must be considered when designing weirs with wide crests.

If placed in a series, the appropriate distance between weirs depends on stream gradient and height of the weirs. In general, spacing should be such that water backed up by one weir will not affect the depth of the water in the plunge pool of the upstream weir. It is important to consider leaping abilities of the fish to be benefitted by the project. In general, no jump should be higher than 12 inches.

Vortex Boulder Weir

Vortex boulder weirs were designed by Wildland Hydrology for use in high bedload streams to maintain sediment transport capacity and low width/depth ratios (Figures VII-22, VII-23, and VII-24). These structures are most appropriate in >F= and >B= type channels. Vortex boulder weirs:

1) Provide instream cover and deepen feeding areas in riffle habitats;

2) Provide a wide range of velocities for salmonid holding water at high flow without creating backwater or sediment deposition;

3) Act as a grade control structure without upstream lateral migration, bank erosion or aggradation, characteristic of some log or boulder weir designs;

4) Maintain a low width/depth ratio to reduce sediment deposition and maintain the sediment transport capacity of the channel.

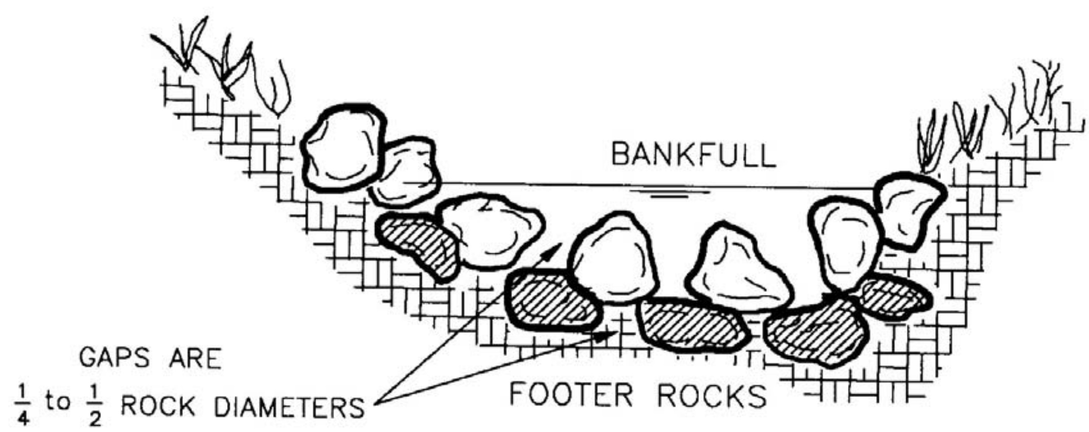


Figure VII-22. Vortex boulder weir, cross section view (Rosgen, 1993).

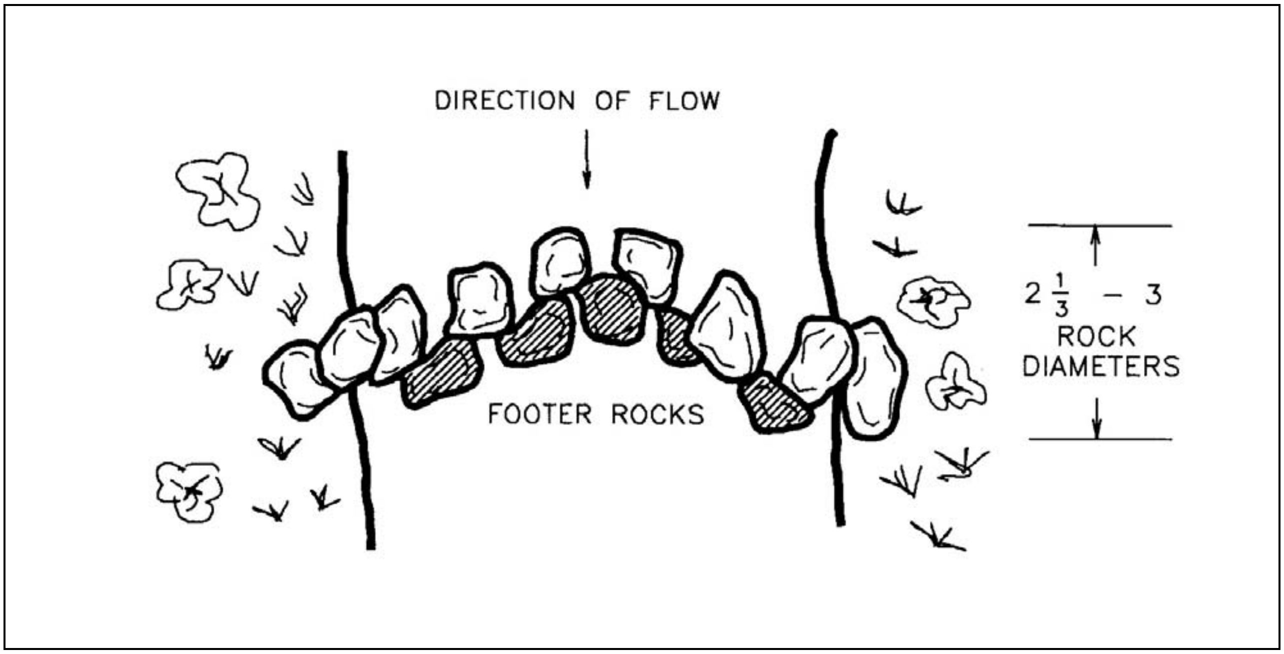


Figure VII-23. Vortex boulder weir, plan view (Rosgen, 1993).

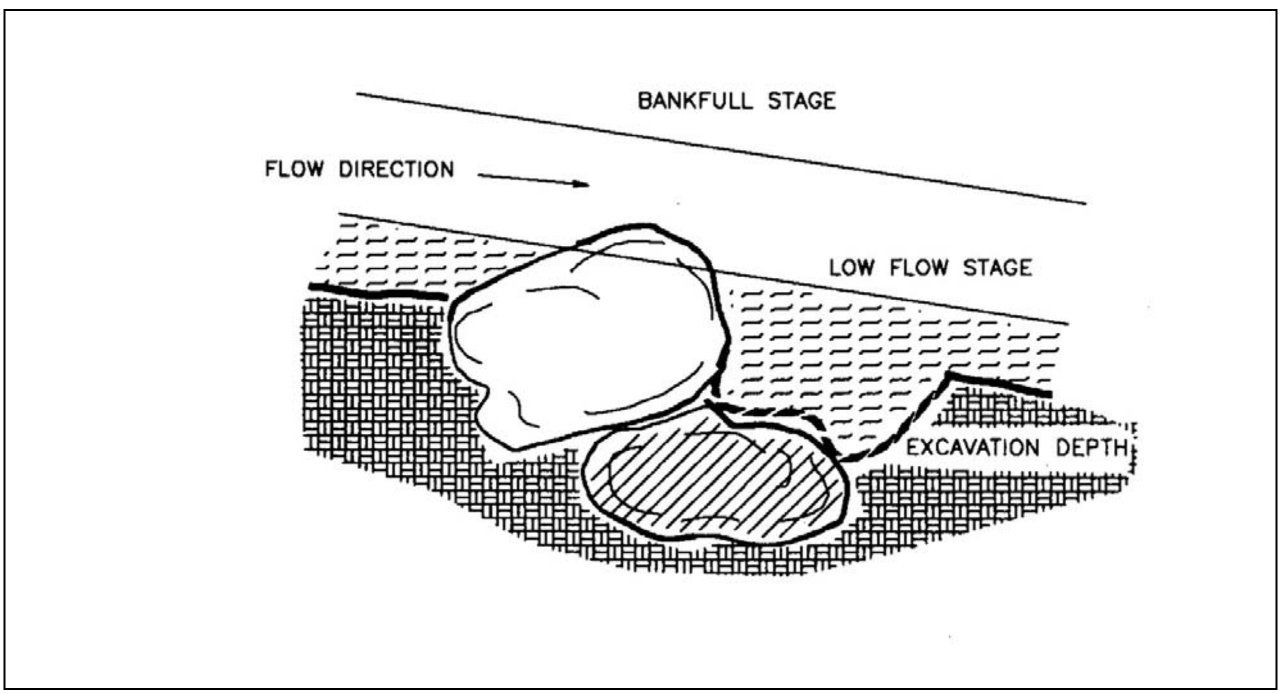


Figure VII-24. Vortex boulder weir, profile view (Rosgen, 1993).

Boulder Clusters

Boulder clusters are used to create scour pockets around boulders, to provide rearing habitat for juvenile salmonids, to build quiet water resting areas for upstream migrating spawners, and to sort spawning gravel (Figure VII-25).

Generally, clusters are located in straight, stable, moderately to well confined, low gradient riffles (0.5 to 1 percent slope) for spawning gravel enhancement; they are also placed in higher gradient riffles (1 to 4 percent slope) to improve rearing habitat and provide cover. At least 3 to 5 foot diameter boulders are recommended, except in very small streams.

To be effective in creating scour pockets and habitat niches around individual boulders, the correct distance between adjacent boulders and the configuration of the boulder clusters must be determined. In general, adjacent boulders should be 0.5 to 1 foot apart. The best configuration for boulders is usually a triangle of three boulders. Several of these clusters may be aggregated to increase scour area and create greater habitat complexity.

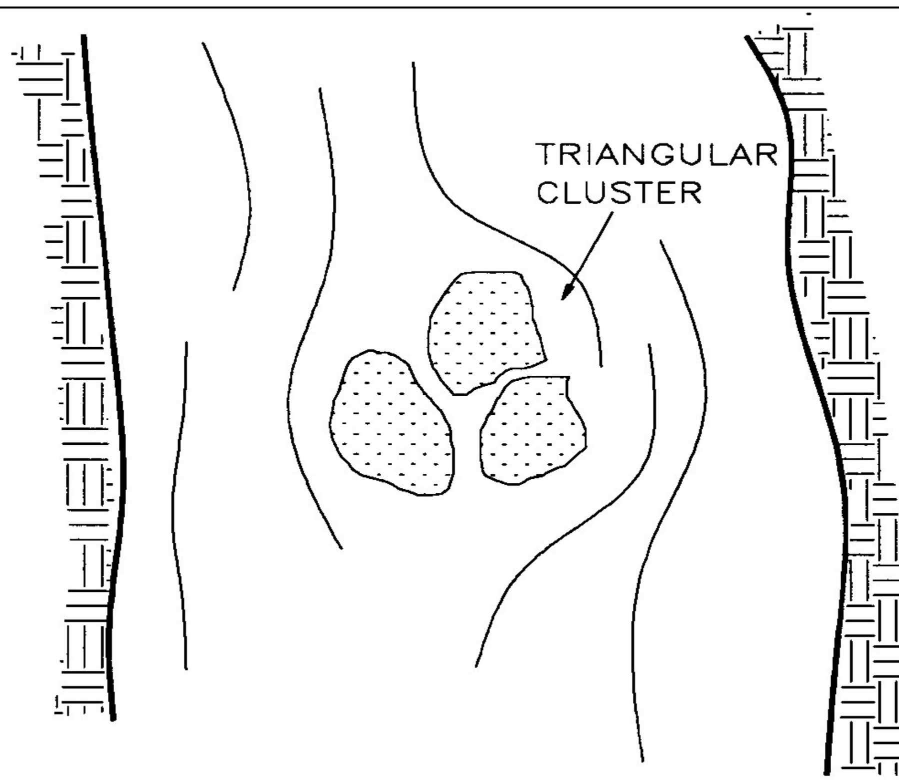


Figure VII-25. Boulder cluster.

If large angular quarry boulders are available, a single boulder can create good cover for juvenile and adult fish. Place the boulder within the middle two quarters of channel width, and not in a deposition zone. If the boulder is placed on a sand or silt bar, it may disappear into the bar. Do not use boulders that are so big that they divert the stream from its channel, or into soft stream banks.

Single and Opposing Boulder Wing-Deflectors

Single wing-deflectors are built to protect a portion of one bank, by deflecting the flow away from the bank. They are also used to create scour by constricting the channel thereby accelerating the flow (Figure VII-26). Wing-deflectors can also create quiet water resting areas for use by upstream migrating spawners.

Opposing wing-deflectors are built to constrict the flow to create a scour pool and sort spawning gravel. These structures are best installed in long, uniform glides or riffles. They create rearing habitat for juvenile salmonids as well as resting areas for upstream migrating spawners. The upstream side of the deflector will develop deposition that may become suitable spawning habitat.

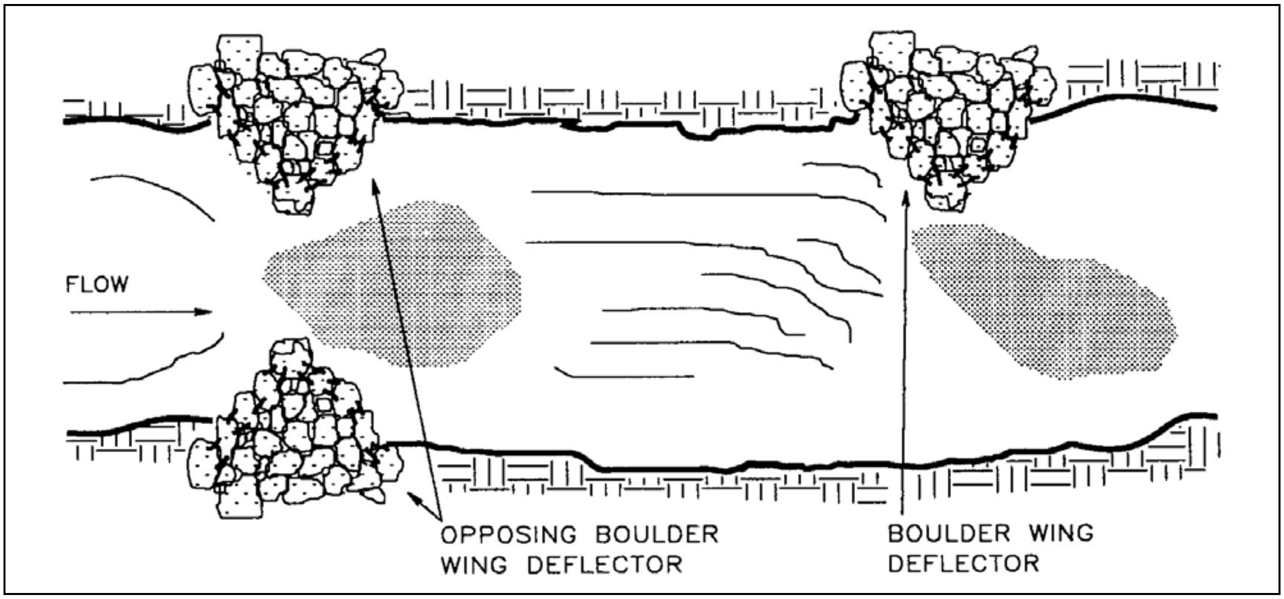


Figure VII-26. Single and opposing boulder wing-deflectors.

Wing-deflectors are similar to boulder weirs in that they are keyed into the stream banks, and slope to a low point near the center of the channel. Opposing wing-deflectors are created by constructing two single wing-deflectors opposite each other, reducing channel width by 40 to 80 percent. They should be constructed in low profile and their apexes should be equal in height.

Wing-deflectors are built in a triangular shape. This configuration will more effectively funnel flows between the apexes of opposing wing-deflectors, or to the apex of a single deflector.

Size of boulders will depend on the size of the channel, but oversized boulders are usually not a problem. To maintain the integrity of the structure it is desirable to secure the boulders with cable and polyester resin adhesive to create the perimeter of the structure. Smaller boulders or cobble can be used to fill the interior. The stream banks must either be naturally resistant to erosion or bank protection should be incorporated in construction of wing-deflectors.

Log Structures

Applications for log structures are similar to those for boulder structures. Logs may be used to provide instream cover for juvenile salmonids and spawning adults, to scour pools for rearing habitat, to recruit spawning gravel, and to stabilize eroding stream banks.

Log structures have a variety of shapes and uses. These include straight log weirs, downstream-V weirs, diagonal weirs, upstream-V weirs, upsurge weirs, wing-deflectors, divide logs, digger logs, and Hewitt ramps. The various structures have specific purposes which often dictate the specifications to which they are built. Many of these structures serve the dual purpose of trapping, sorting, and stabilizing gravel for spawning habitat as well as creating scour pools which act as rearing habitat for juvenile salmonids and escape cover or resting areas for spawning adults.

Log Weirs

As with boulder weirs, log weirs must be designed to specifications dictated by channel dimensions and range of flows that the stream may experience. It is important that log weirs are designed so that they do not become low-flow migration barriers. The maximum jump height that a log weir should create is 12 inches.

Log weirs are often placed in long, shallow riffles or runs. They may also be installed on straight reaches or meanders. The gradient should be between 1.5 and 4 percent in a moderately entrenched channel. Stream banks should be stable and composed of coarse, resistant material.

Log weirs have advantages and disadvantages compared to boulder weirs. The advantages are that logs are often available near the channel and are often obtainable at no cost other than the labor to bring them to the project site. A disadvantage of logs is that they will eventually rot, making the structure less durable than one of boulders. Redwood and cedar logs, however, can last for decades in a stream, are aesthetic, and are easy to work with.

Log weirs can be built in a variety of configurations. The type of log weir constructed is dependent on the desired habitat modification. Straight log weirs have been used extensively throughout the California coastal mountains. Constructed properly, they will trap gravel upstream and scour a pool downstream. Several problems have been associated with straight weir design. Straight log weirs can push too much water to sides, eroding fragile banks. Where there is not a proper downstream control, down-cutting immediately below the weir may create a jump in excess of 12 inches and a low-flow notch will be required (Figure VII-27). Generally, the only purpose for a straight log weir is to back-flood an area, such as a culvert. Downstream-V and diagonal weirs are more efficient at trapping gravel and upstream-V weirs are better for scouring pools.

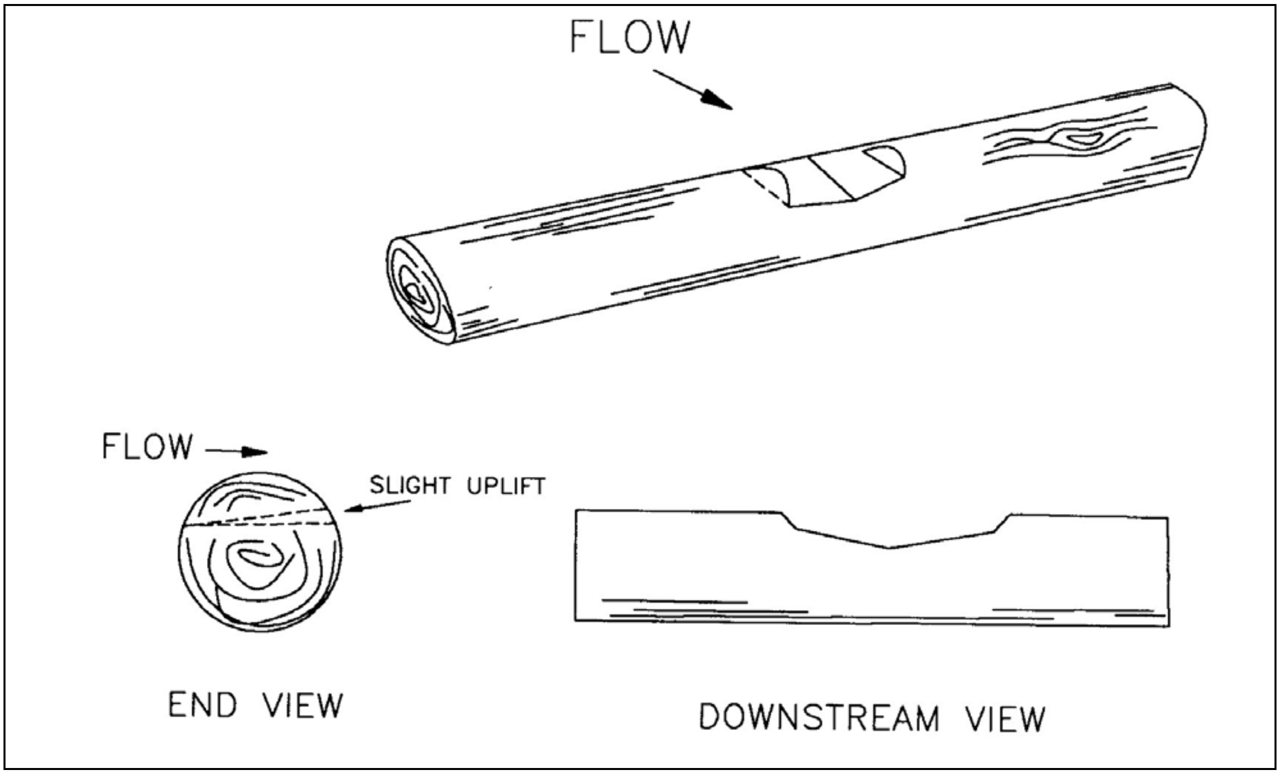


Figure VII-27. Straight log weir with low-flow notch.

Downstream-V weirs are effective in dissipating high flow energy and are used to collect spawning gravel. The downstream design forces water to the banks, therefore downstream-V weirs should only be constructed in areas of good bank stability (Figure VII-28).

Diagonal log weirs are placed diagonally to stream flow and span the full channel width. The upstream end of a diagonal log weir is set at a lower elevation than the downstream end. The drop in elevation should be approximately 6 inches in 10 feet. Diagonal log weirs cause stream flow to adjust direction so flow comes off the log at a right angle. Diagonal log weirs are good for creating lateral scour pools on river bends and for collecting spawning gravel, and they are also used to adjust direction of the stream. They can be very useful in directing flow away from unstable banks (Figure VII-29).

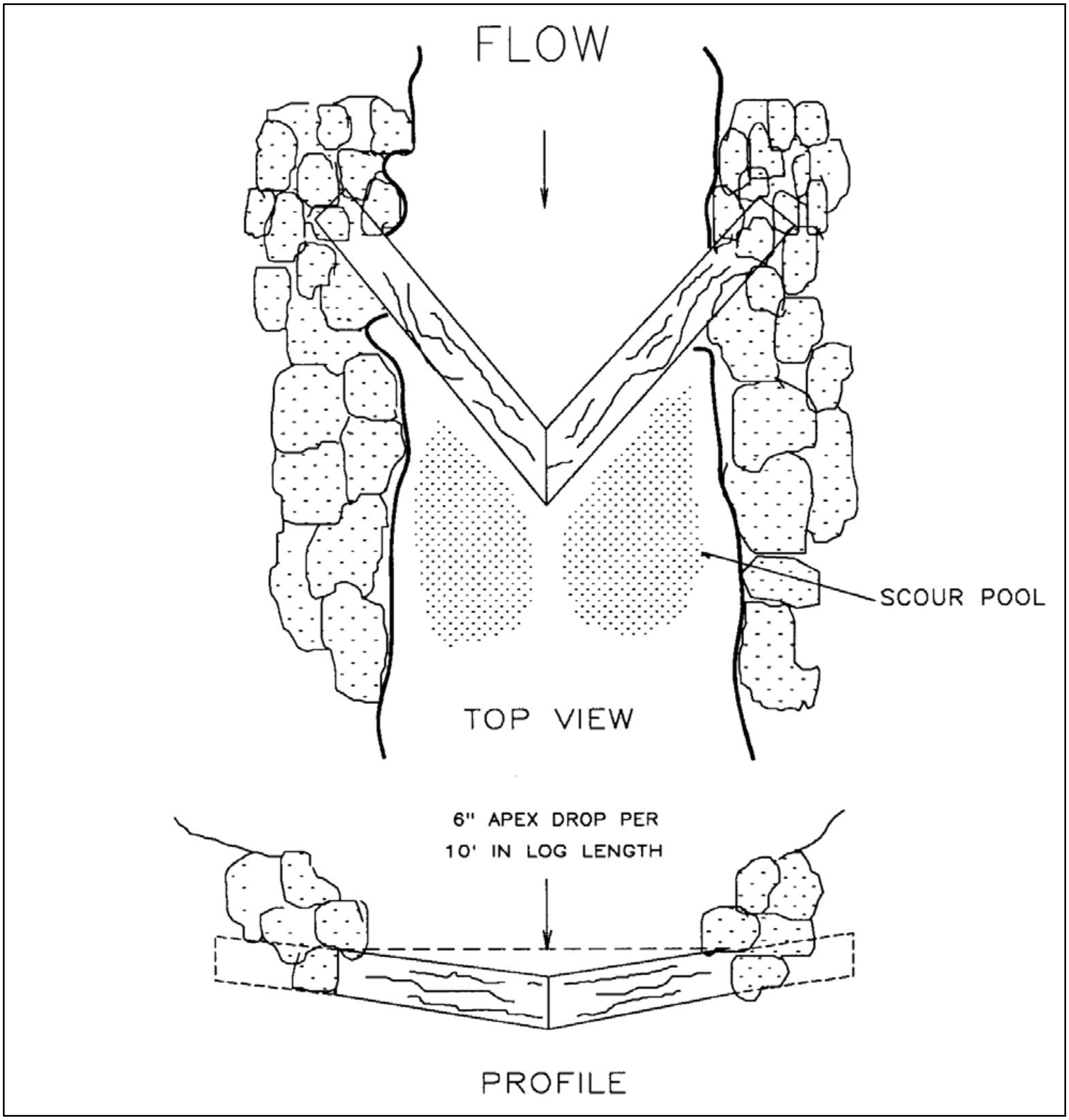


Figure VII-28. Downstream-V log weir.

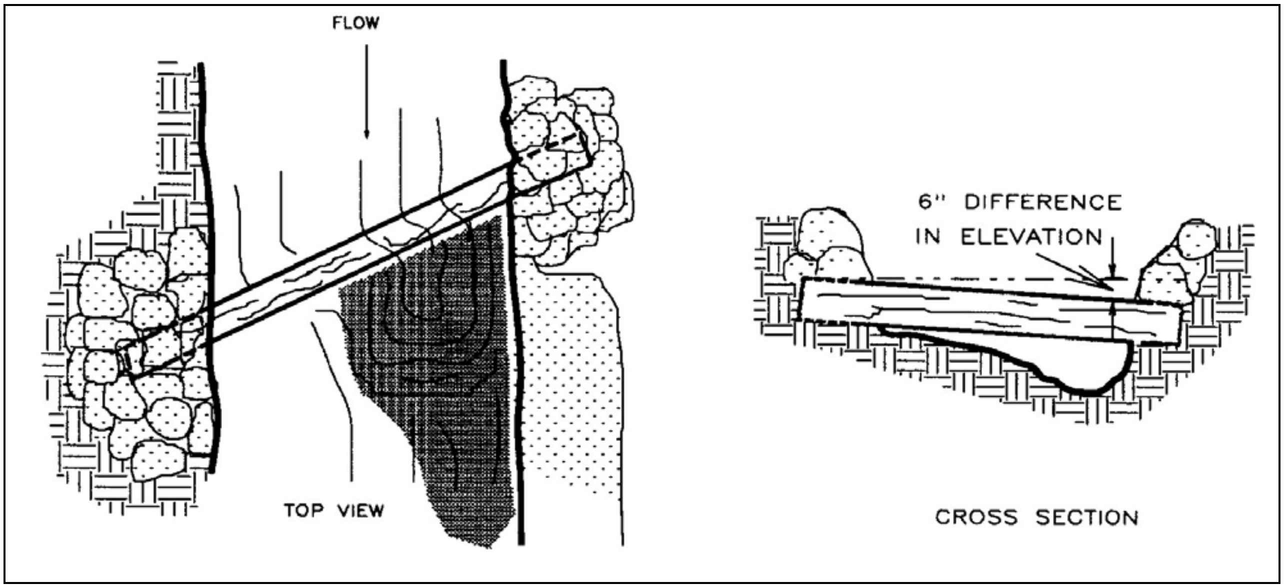


Figure VII-29. Diagonal log weir.

Upstream-V log weirs are used to scour deep pools. Principles of construction are the same for the various shapes of log weirs. Construction of an upstream-V weir will be described. These techniques of construction apply to other log weirs with some variations required to accommodate differences in configuration (Figure VII-30).

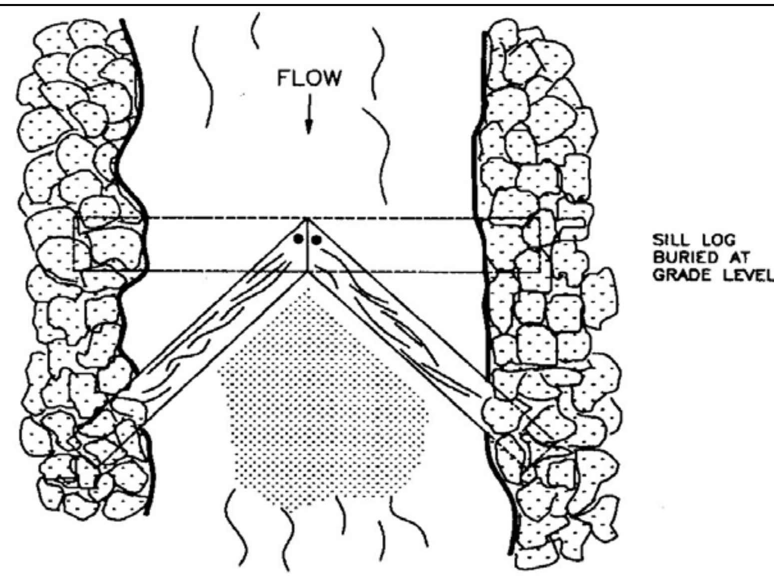


Figure VII-30. Upstream-V log weir.

Use redwood or cedar logs if available. Logs should be of appropriate size, determined by channel width, channel type, and bankfull discharge flows. Dig a trench perpendicular to the channel to bury the sill log at streambed grade. Key the ends of the sill log at least 6 feet into the bank. Place rock on keyed section of the log to prevent it from floating loose. Rock must be large enough and in sufficient quantity to protect banks.

Place the apex ends of the two logs forming the upstream "V" on top of the sill log. The two logs are placed so the apex is approximately 6 inches lower than the downstream keyed-in ends of the logs. The top of the logs at the apex should be no higher than 12 inches above the downstream water line. The apex of the logs must be shaped for a close fit. Drill through the apex ends of the two logs into the sill log, and hammer lengths of one-inch threaded rebar through both drill holes. Secure washers and nuts to the ends of the threaded rebar and tighten securely. Armor the bank ends of the logs with rock. Dig a 24-inch deep pool at the downstream apex so that fish can jump over the logs until high flows can create a scour pool.

If a series of weirs is to be installed, the downstream weir should be constructed first. Difference in elevation between lower and upper water surfaces should be 12 inches. Elevations can be determined with a hand or survey level and a stadia rod.

There are numerous variations of the upstream-V log weir. These include the upstream-V leaving a low-flow notch (Figure VII-31), the upstream-V using opposing log deflectors over a sill log (Figure VII-32), and log constrictors over a series of log planks (Figure VII-33).

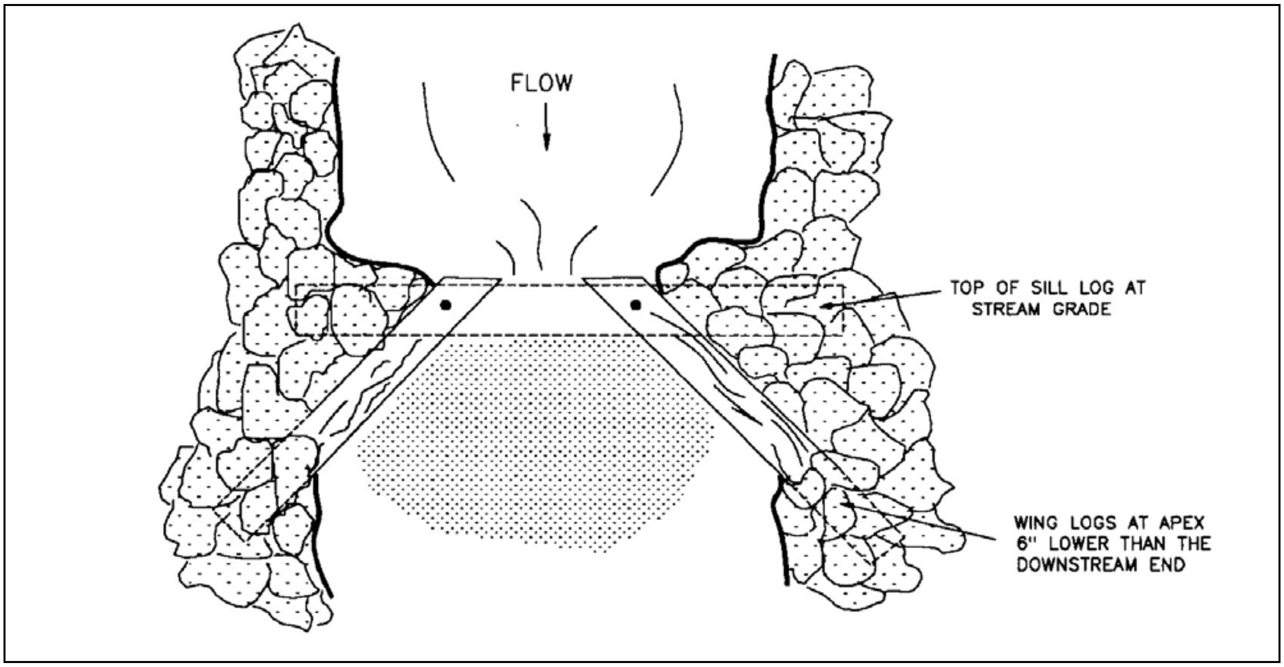


Figure VII-31. Upstream-V log weir with a low-flow notch.

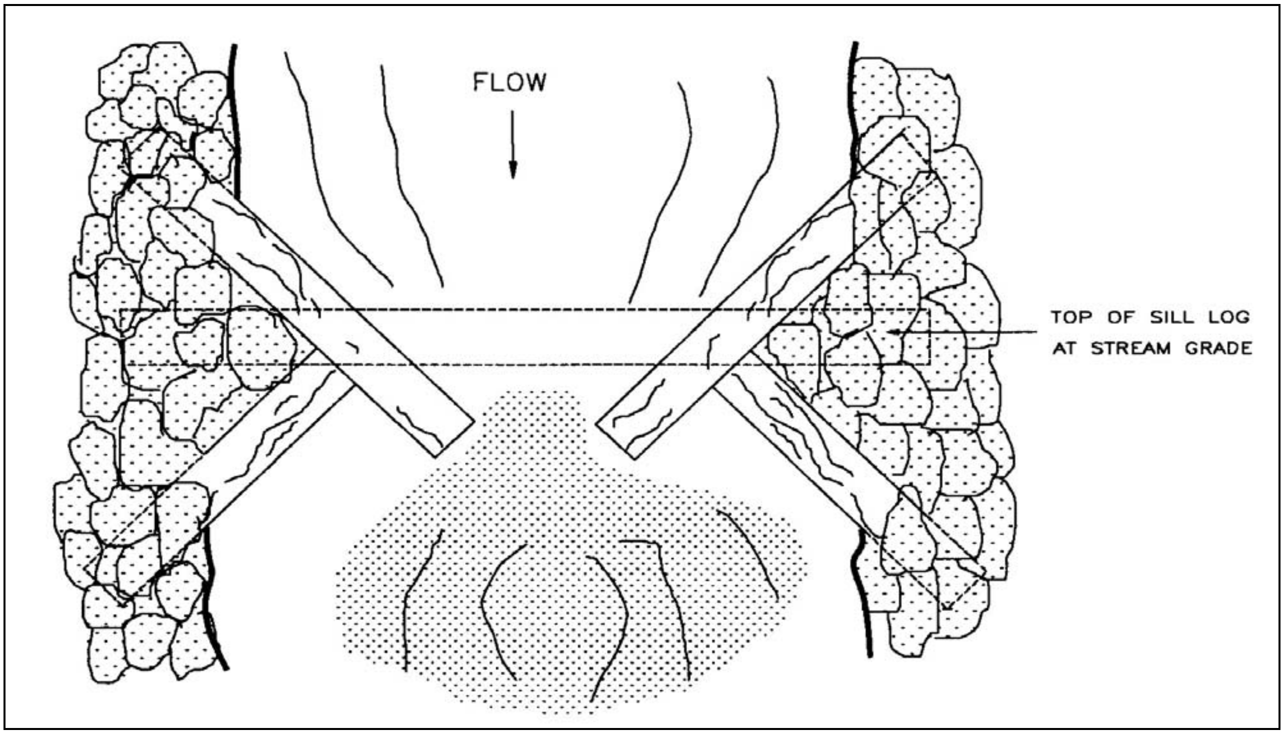


Figure VII-32. Upstream-V log weir with a low-flow notch.

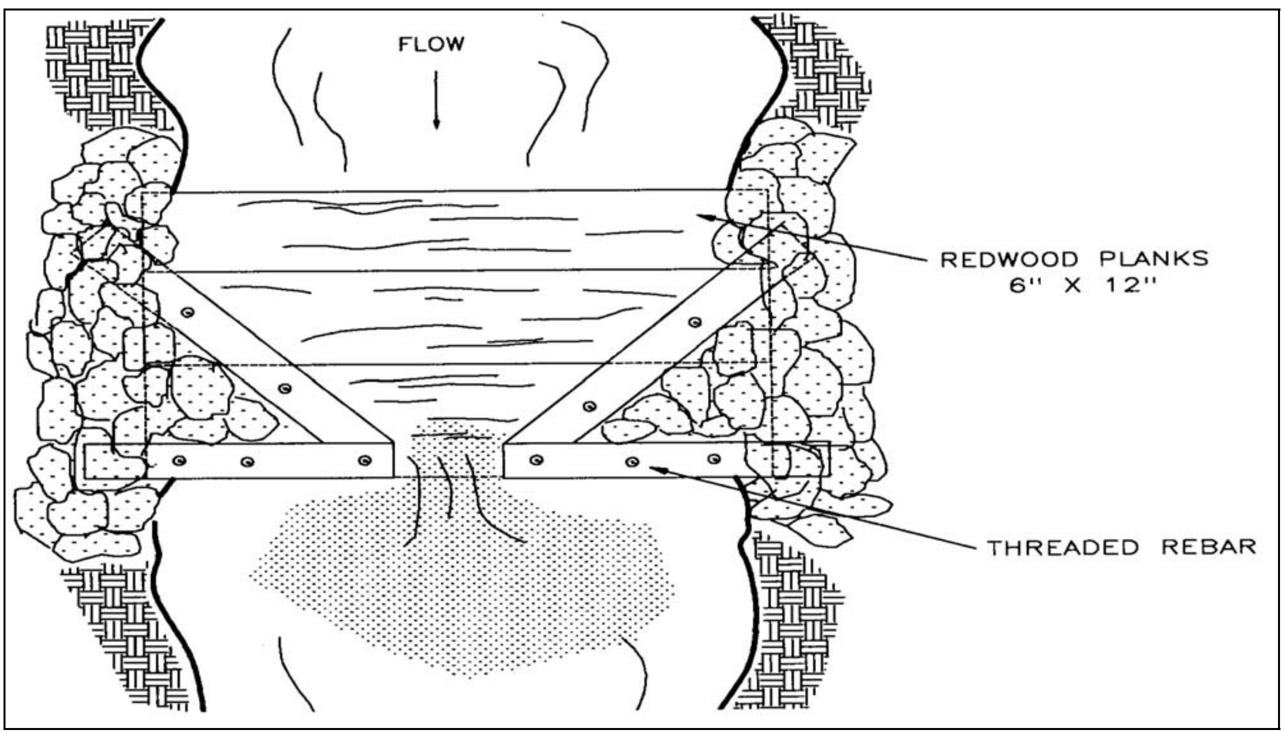


Figure VII-33. Log constrictors over planks.

Upsurge Weirs

Upsurge weirs are logs which span the full channel width. They are used to force stream flow under the log in order to scour the channel bottom to create or enhance pools for summer rearing habitat. Upsurge weirs are most effective when the bottom of the log is placed at the summer low-flow surface elevation (Figure VII-34).

Strong anchoring systems are required for upsurge weirs because of the strong hydraulic lifting force generated at scouring flows. Upsurge weirs should be anchored to stationary boulders on the banks or to bedrock. If this is not possible, both ends of the weir can be set into excavated trenches on opposite banks at the summer low-flow water level. Four to six feet of the log should be keyed into each bank. Enough weight must be placed on each log end to permanently secure it.

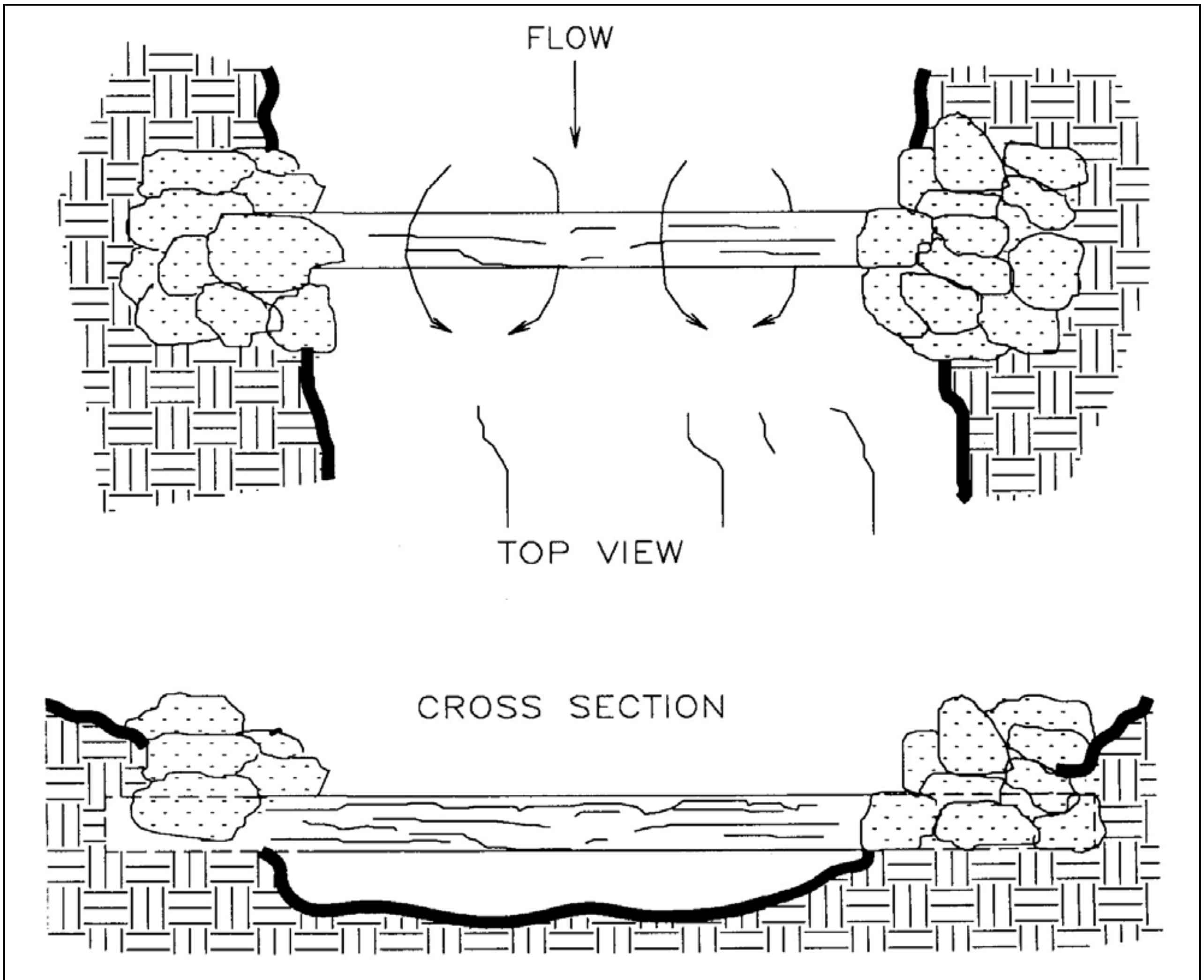


Figure VII-34. Upsurge weir.

Single and Opposing Log Wing-Deflectors

Wing-deflectors are used to concentrate the flow of water into a selected area of the channel to create scour. The scour creates a pool and the deflector(s) will act as cover and create a resting area for fish. They are primarily used in areas of long, uniform glides or riffles to diversify habitat and create velocity shear zones (Figure VII-35).

Wing-deflectors must not be placed or designed so that they create a severe channel constriction or deflect high flows into unstable or unprotected stream banks. The upstream log should extend into the summer low-flow channel so that it provides summer rearing habitat.

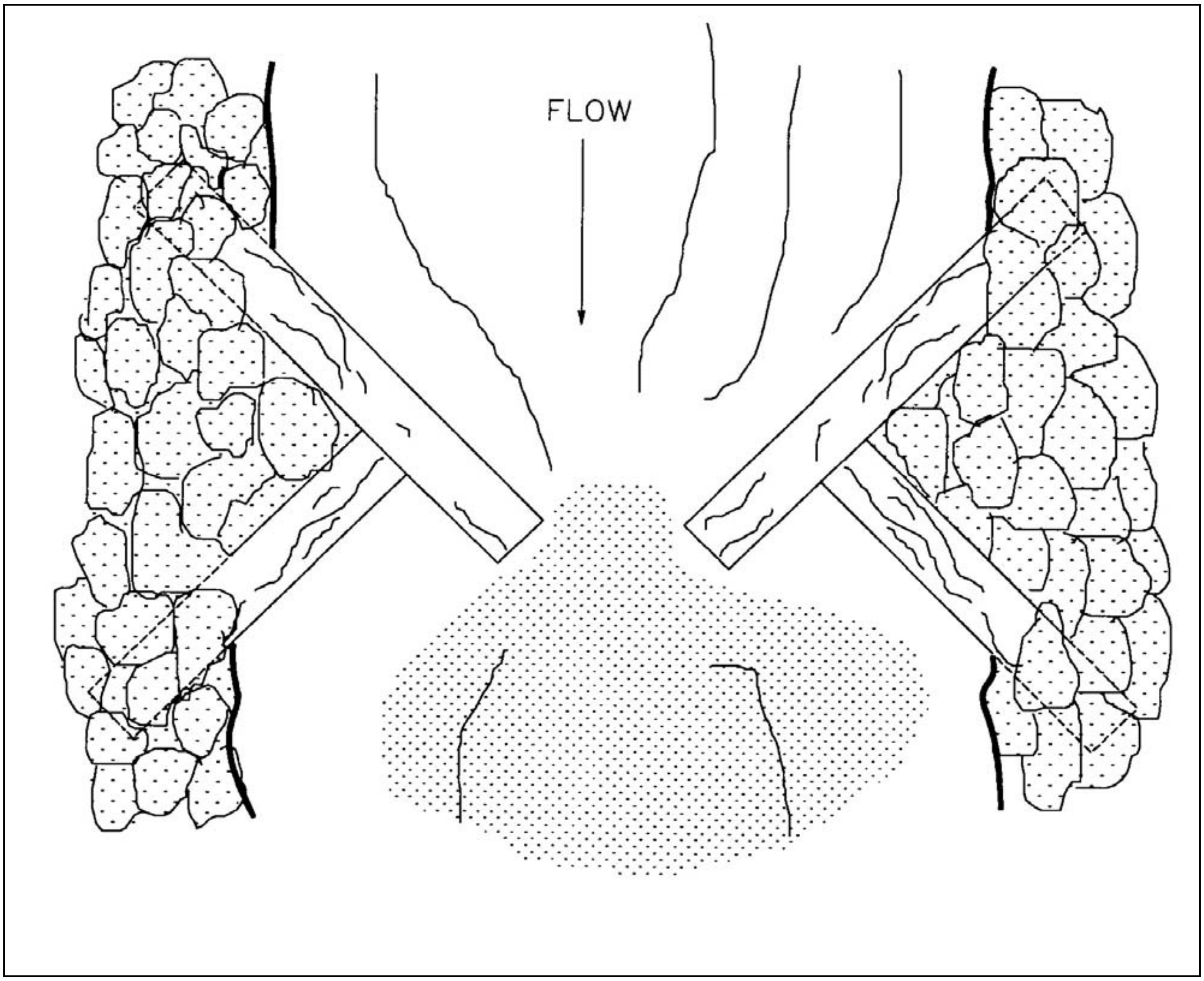


Figure VII-35. Opposing log wing-deflector.

The construction of the deflector involves making a "V" or a triangle whose base is parallel to the bank and whose two sides join to make the apex, which extends into the flow. A trench must be excavated into the bank to key-in the logs that make up the sides of the triangle. The trench must extend far enough into the bank to afford adequate anchoring for the deflector side logs. The angle of this trench will determine the angle at which the deflector sits. Orientation of the trenches will be determined by the desired apex angle. The apex angle will be 100 to 120 degrees. Location of the apex should be determined and the trenches should be laid out to conform to the desired angle of slope and the apex angle.

The ends of the side logs must be notched so that they fit together to create a joint that is the same diameter as the side logs (the top of the apex joint should form a smooth transition to either log). One log end (the one pointing downstream) can be extended past the apex to create scour and additional cover. The apex is held together with threaded rebar inserted through a hole drilled in the apex.

The base of the triangle parallels the bank. A smaller diameter log can be used to join the two sides of the apex. This will give the structure added strength, but if the bank ends of the logs are adequately anchored, the base log may not be needed.

Once logs are placed in their trenches and the ends have been joined to make the apex, the bank ends should secured to trees, stumps, boulders, or a deadman, then covered with boulders to weigh them down and act as anchors.

If opposing deflectors are installed, the distance between the apexes is important. This distance will determine velocity of water flowing between the deflectors and the amount of scour created. Opposing wing-deflectors typically should reduce channel width by 40 to 80 percent.

Hewitt Ramps

Hewitt ramps are constructed by installing base logs that support cedar or redwood planks. Planks are placed on the upstream side of the base log at an angle that will allow gravel to wash over the structure, creating a plunge pool on the downstream side of the structure. They are used to create pools in areas where there is a large volume of bedload movement. Construction costs for Hewitt ramps are high and the structures usually require periodic maintenance. Hewitt ramps must have a low profile or other design features to avoid creating a barrier to fish migration (Figure VII-36).

A Hewitt ramp is constructed with a base log placed in a trench excavated in the stream to one-third the log diameter. This log is secured by burying its ends in the stream banks. The log should be at least two feet in diameter. On the upstream side of the log, cedar or redwood planks (2 x 6 inch minimum) are laid to create a ramp at an angle of 30 to 45 degrees. Planks are set against each other and the ends are buried in the substrate to a depth of at least two feet. The area between the planks and the log should be filled with cobble to provide extra support for the planks. Tops of the planks are nailed to the log with 20d galvanized nails. The planks are cut off in a "V" configuration to concentrate stream flow into the thalweg during low flow conditions.

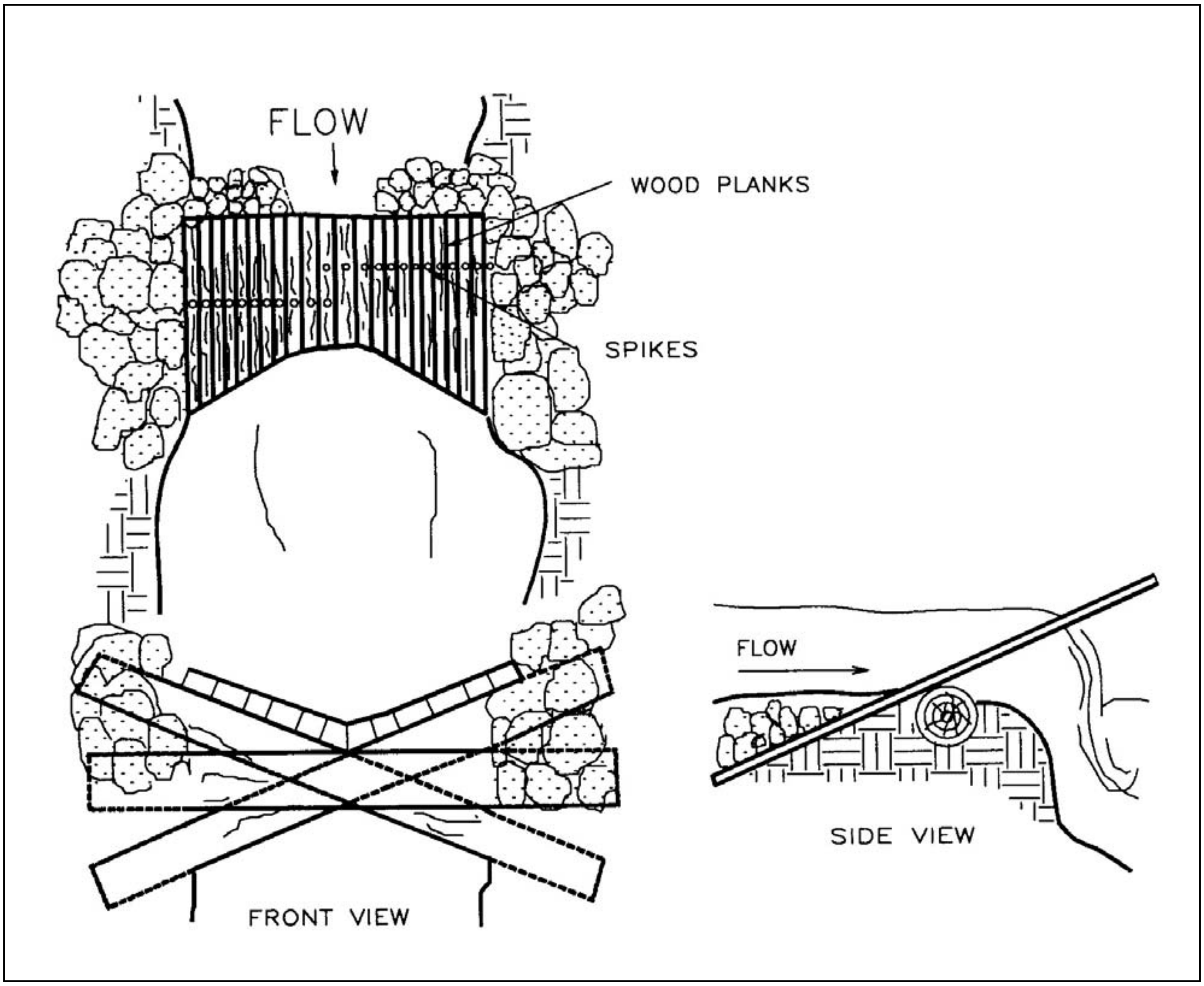


Figure VII-36. Hewitt ramp.

Placement of Imported Spawning Gravel

In streams that are deficient in spawning gravel, either naturally or because of artificial structures which prevent gravel recruitment or transport, addition of spawning size gravel may be beneficial. Several techniques may be used.

Gravel may be placed upstream of weir installations to a depth of about 18 inches. Spawning gravel for salmon should be clean, creek-run from 2 inch to 4 inches in diameter. Gravel would normally be dumped at a staging area on the bank and then picked up and placed with a front-end loader or hydraulic excavator.

In some streams that have high levels of fine sediment transported at normal flows, or in many streams after a high flow or watershed disturbance, fine sediment may be deposited in spawning gravel substrates. Therefore, periodic maintenance might be required to reduce fine sediment in spawning areas. This usually is done by plowing the gravel with a ripper attachment on a tractor and adding fresh gravel. Ripping is also an excellent technique for improving quality of natural spawning riffles infiltrated by fine sediment. Watersheds that have high levels of fine sediment yield should be treated to control the sediment source, if possible, before gravel seeding is considered as a project.

Gravel may be spread on spawning riffles without control weirs. This normally is appropriate where a dam or other artificial structure has blocked natural downstream movement of gravel, and gravel from once-productive spawning riffles has been washed away. It may be advisable to scrape off some of the armoring layer of cobble before fresh gravel is added. This technique should only be used in reasonably stable riffle areas, or there is an unacceptable risk of having the eggs and gravel wash downstream with high flows after fish use the gravel for spawning.

Sometimes, spawning habitat can be improved by simply dumping gravel in an area of high water velocity and allowing the stream to distribute the gravel downstream during high flows. An area of active bank erosion is usually a good site for this technique because the stream has demonstrated the ability to move substrate material. The project may also provide temporary protection for the bank until the gravel is washed away.

Fish Screens

Unscreened water diversions have been recognized as a serious problem for California's salmonid populations since the early 1900's. As a result, screens have been used to prevent entrainment of juvenile salmonids in water diverted for agriculture, power generations, or domestic use since the 1920's, and are needed on both gravity flow and pump diversion systems. Through the years, fish screen technology has improved dramatically, and high performance, low maintenance designs are now available. Screening criteria by DFG and NMFS (Appendix S) has established specifications which must be included in fish screen designs. This criteria requires water diversion screens to complete a barrier to salmonid entrainment.

Currently, most fish screens consist of perforated metal plate, or mesh material, with openings sized to prevent entrainment of juvenile salmonids. Screen systems that utilize light, electric fields, sonic systems, and bubble curtains as barriers have been tested, but are not adequate. Screens utilize debris cleaning devices, typically brushes, water jets, or compressed air to prevent them from plugging. Bypass routes return fish to the stream channel. Normally a flow measuring device and head gate are required to monitor and control diversion flows. Screen designs are complex and site specific, and many require professional engineering; therefore, none are included in this manual. Consultations with staff from DFG fish habitat improvement shops and NMFS are recommended to determine fish screen suitability at a proposed diversion site.

FISH PASSAGE

Obstructions to upstream migration frequently restrict distribution of salmonids. When barriers to fish movement exist, reaches downstream of the blockage may become overcrowded with spawners or juvenile fish, while suitable areas upstream lie unused. Even a partial obstruction, which only poses a barrier under certain flow conditions, can be a serious problem.

Increasing the use of spawning and nursery areas above natural and human-induced obstructions is a sound approach to restoration which has met with considerable success. A note of caution that must be included, however, is: avoid situations in which newly created access for one species results in competition with a species or population already established in the area above the obstruction. Possible species interactions might include steelhead versus non-anadromous rainbow trout, or coho salmon versus established populations of cutthroat or steelhead trout. Competition with the introduced species may reduce the population of the established species or population.

The key physical characteristics of the stream which inherently affect salmonid migration should be understood before any attempt is made to remove or modify an obstruction. Low waterfalls (less than six feet), cascades, and chutes in natural watercourses can affect fish migration in several ways. When water drops vertically into a pool of depth at least 1.25 times height of the drop, fish have very little difficulty jumping over a low obstruction. The upwelling water, or Astanding wave@ created by flow plunging into the pool will actually assist fish by imparting an upward force as a fish leaps from the pool. However, an incline or chute can form a hydraulic jump further downstream; encouraging fish to jump too far from the crest of the drop (Figure VII-37).

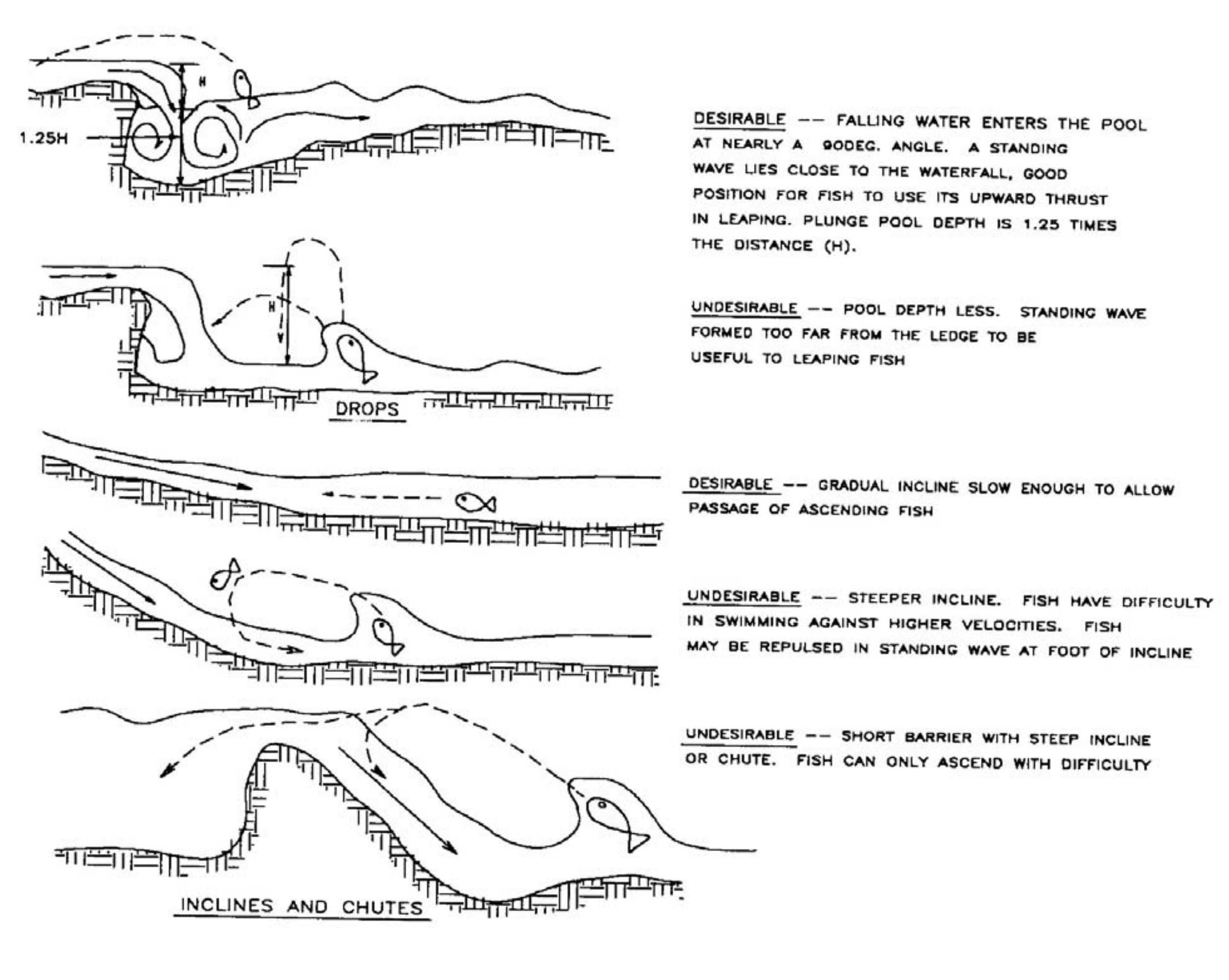


Figure VII-37. Movement of fish over natural obstacles (*Stream Enhancement Guide*, British Columbia Ministry of Environment, 1980, p. 27).

Obstructions

Natural obstructions to fish movement include waterfalls, chutes, logs and debris accumulations, and beaver dams. Any of these can create total or selective barriers. Often these barriers can be modified to provide fish passage, but regarding both log jams and beaver dams, care must be taken to preserve their rearing habitat benefits as well as to provide upstream passage. Removal of any natural obstruction during salmonid egg incubation may cause loss of the redd through silt deposition or changes in flow characteristics. Except for emergencies, any work to remove natural obstructions should be completed during low-flow periods outside the spawning or incubation season.

Log Jams

Log or debris jams can be either human-induced or a natural feature. It is sometimes difficult to establish whether or not a log jam is blocking migration. Often, a log jam which appears impassable has stable underwater passages for migrating fish. Careful surveys for salmonids, especially fry, above suspected jams should be conducted prior to any treatment. Large woody debris accumulations are preferred rearing habitat for steelhead trout and coho salmon because of the excellent cover they afford. Large stable pools created by log jams also provide important holding areas for adult salmonids.

Log and debris jams which become plugged with silt, gravel, fine debris, or other materials can form an impassable barrier or block flow and create a waterfall. In some cases, water diverting around log jams can create detrimental bank erosion. If a jam is creating an impassable barrier or creating erosion, modification of the log jam is desirable. In all instances, only the minimum amount of wood necessary to facilitate fish passage, or to eliminate a stream channel problem, should be manipulated.

The fastest and most efficient way to modify a log barrier is with heavy equipment. A self-propelled logging yarder, with a high lead, is most desirable. Hydraulic excavators are also useful. When this equipment is not available and access into the site is poor, manual labor, combined with a chain saw and griphoist operation, can satisfactorily modify log jams.

Beaver Dams

Beaver dams, like log jams, create benefits for salmonids as well as problems. Rearing juveniles, especially coho, use beaver ponds extensively. In addition, the pond can store water to help stabilize stream flow, augment the groundwater contribution to a stream's base flow, and reduce peak flows during freshet conditions.

Only when determined to be a problem, after thorough consultation with fish and wildlife personnel of the California Department of Fish and Game, should beaver dams be modified. If required, beaver dams can be altered with simple hand tools, a small backhoe, or by blasting.

Where frequent inspection of the beaver dam is possible, it is preferable to maintain an opening for fish passage over the crest of the dam. This results in a minimum of damage to the downstream areas, while still maintaining beneficial aspects of the impoundment.

Beavers are hard-working and persistent animals. When either a portion or all of a beaver dam is removed, the beaver family will normally attempt to restore the damaged structure. They often succeed.

Waterfalls and Chutes

Waterfalls and chutes can create fish migration barriers. Blasting to provide fish passage is usually the preferred method of altering waterfalls and chutes. Resting pools can be blasted into bedrock, forming a step-and-pool access (Figure VII-38).

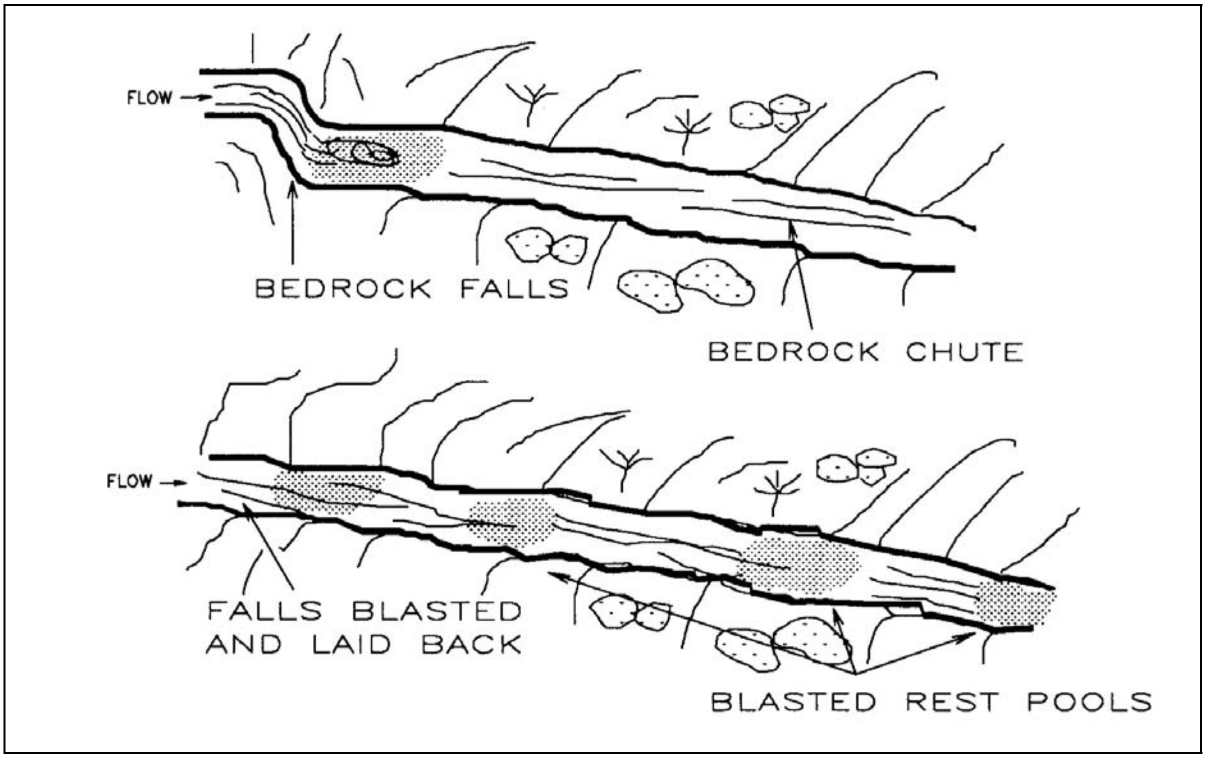


Figure VII-38. Before and after blasting of falls and bedrock chute.

Where a chute is causing a velocity barrier, it is sometimes possible to widen the chute by blasting to decrease the water velocity. Blasting can also be used to lower waterfalls. All blasting must be performed by a State of California, Division of Occupational Safety and Health, licensed blaster.

In some instances, use of log, boulder, or cement weirs to decrease velocity and back-flood a chute or waterfall is possible. As a last resort fishways can be installed to create fish passage.

Landslides

Landslides often occur during fall and spring freshets, which may also coincide with major fish migrations. If possible, slides should be removed or remedial work carried out immediately to avoid harmful effects on fish. If the slide is big enough, large earth moving equipment may be required to completely remove the obstruction.

Not all landslides require use of heavy equipment or large amounts of capital to improve fish migration. Often, in small landslides, selective removal or relocation of boulders and debris by hand crews, using steel rock bars or griphoists, can provide fish passage through or around an obstruction.

Large boulders may be reduced to a size that can be readily moved using a portable gasoline-powered rock drill and feather and wedges (hand rock-splitting tools). This may also be done with explosives, if a qualified blaster is available.

If it is not feasible to remove the obstruction, a possible alternative might be the use of a temporary step-and-pool fishway over or around the obstruction. This can be constructed using rock and debris from the slide. Often, selective blasting combined with handwork will provide a satisfactory fishway.

(Human-Induced Obstructions has been replaced by Part XII of Volume 2.)

~~Human-Induced Obstructions~~

~~Human-caused obstructions include such structures as dams, sills, and improperly installed culverts. The most obvious solution to fish passage problems, for example, culverts, is proper initial installation of the structure. An even better solution would be to install a bridge instead. Unfortunately numerous dams and improperly constructed structures exist. Various types of fishways can be built to provide access past dams and other barriers created by people.~~

~~Fishways~~

~~Fishways provide a way past obstructions that impede upstream migration of salmonids. The structures generally consist of a flume with baffles or a series of stepped pools that slow the water to a velocity more easily negotiated by fish. The three types of fishways to be discussed are: 1) the step-and-pool; 2) Denil ladders; and 3) the Alaskan steep-pass. All fishways require regular maintenance, and should be installed only when absolutely necessary.~~

~~Successful design, construction and operation of a fishway requires close cooperation between designers and biologists. Fishways should be designed to pass fish during at least 90 percent of the flow conditions that will be encountered. Downstream migrant smolts need a minimum 6 inches depth of water. Elements that effect fish passage include height of the jump, velocity of the water, and amount of space the fish has for maneuvering. There are six principal items of biological and hydrological information required prior to the design of a fishway:~~

- ~~Species of salmonids in the river system, as well as magnitude and timing of the runs;~~
- ~~Probable access route to the barrier, including areas where fish will congregate below the obstruction;~~
- ~~Extent of spawning and nursery areas and potential salmonid production from both above and below the obstruction;~~

- ~~Type and quantity of anticipated transportable debris;~~
- ~~Frequency, duration, timing, and magnitude of anticipated flows, especially extreme high and low flows;~~
- ~~Location of other barriers in the stream system, and their possible effects on distribution of salmonids.~~

~~After preliminary information is analyzed, these items must be considered to locate and design the final structure.~~

- ~~The entrance to a Denil ladder and Alaskan steep-pass fishways should be as close as possible to the foot of the obstruction, with the fishway extended into the pool so a swim-in condition exists at all operational flows;~~
- ~~Flows in and near the fishway entrance should be sufficient to attract fish at all water levels;~~
- ~~When fish must swim through high velocity water, changes in direction should be minimized;~~
- ~~Energy dissipation should be complete in a step-and-pool fishway, with no carryover from pool to pool;~~
- ~~Fishways must be deep enough for the largest known fish in the system;~~
- ~~Resting areas must be adequate;~~
- ~~Flow patterns in the fishway must be stable, with no water surges;~~
- ~~A debris deflector should be incorporated at the flow intake;~~
- ~~The upstream exit must allow fish to easily reach secure resting habitat;~~
- ~~Need for cleaning, regulating and repairing the fishway should be minimul.~~

~~Step-and-Pool Fishway~~

~~A step-and-pool fishway consists of a series of vertical partitions spaced down the length of a specially constructed channel or flume (Figure VII-39). Flow spills over the crests of the partitions, each slightly lower than the one above, creating a series of step-like pools which fish can ascend with ease. In streams where there is substantial movement of bedload, tops of concrete walls are capped with 1/4-inch steel angle or plate to provide greater durability. Pools must be carefully sized to dissipate the energy of the cascading flow. Standard specifications for a step-and-pool ladder require pools 8-feet long, 6-feet wide, and 4-feet deep, with no more than 12 inches of rise between steps. Step-and-pool fishways are most effective where water levels remain fairly constant. Depth of water cresting weir sills is critical, particularly in relation to pool size. Crest should not exceed 15 inches in depth or associated water velocities will likely impede~~

~~fish passage. In situations where water levels fluctuate, these fishways require regular adjustment at an upstream control to provide optimum depth and velocity for fish passage.~~

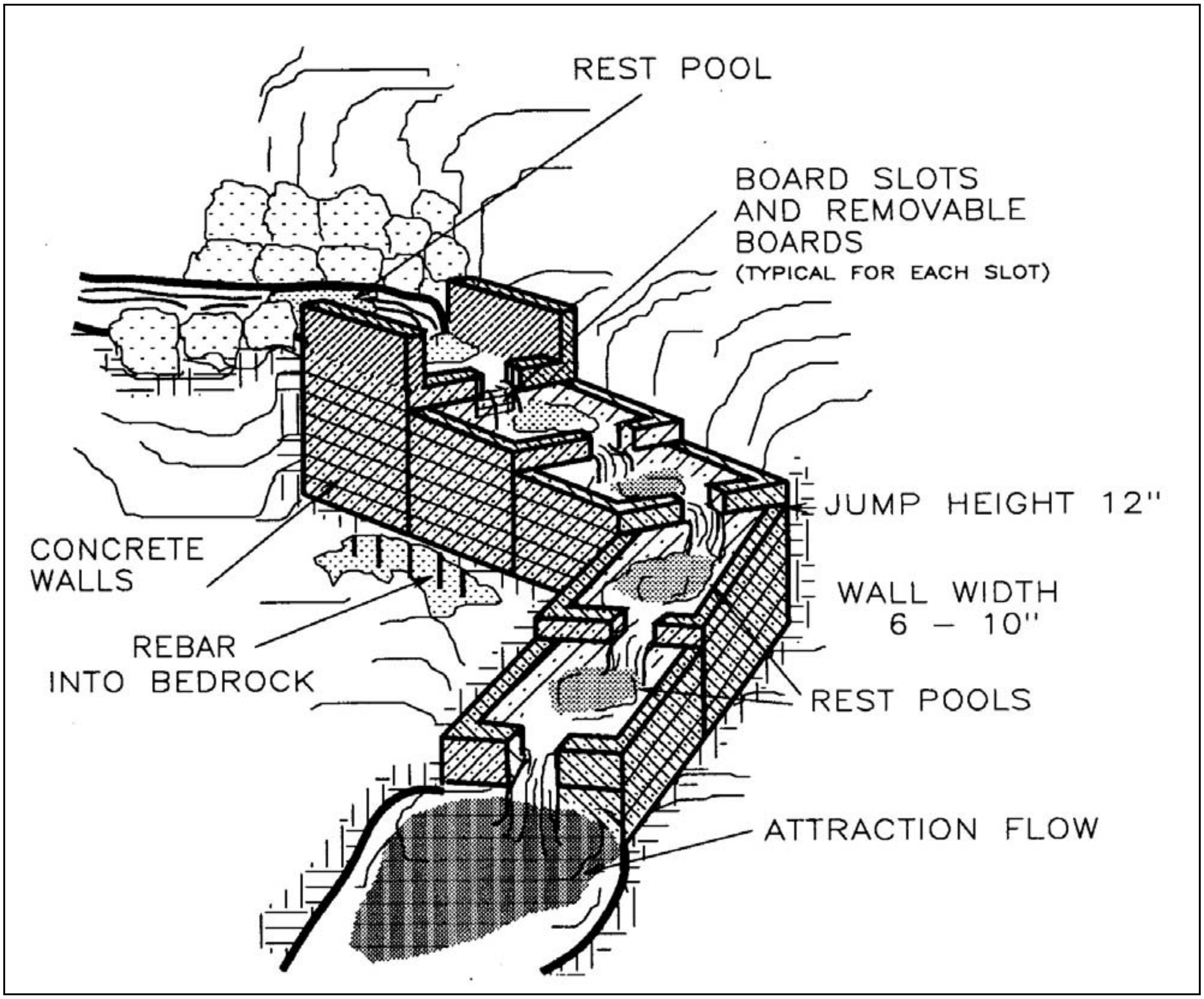
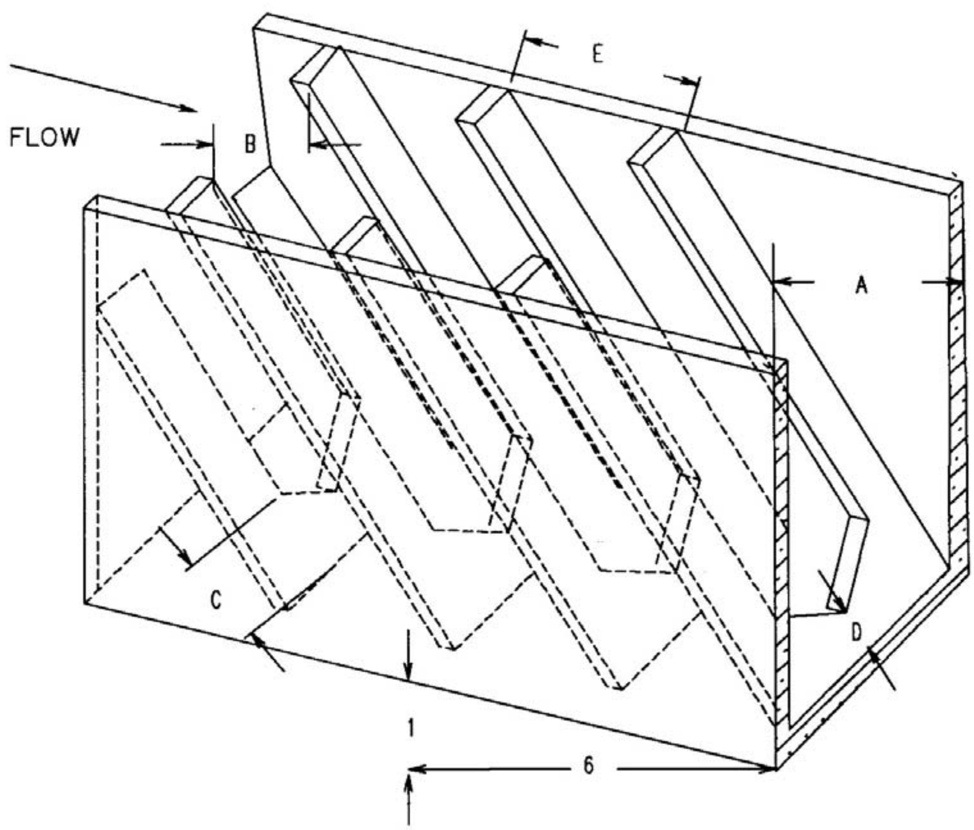


Figure VII-39. Step-and-pool fishway.

~~Denil Fishway~~

~~The Denil fishway is essentially a short section of flume with baffles affixed to the sidewalls and floor (Figure VII-40). The energy of water passing through the structures is dissipated in turbulence caused by baffles, which leave a narrow zone of low-velocity flow. The Denil fishway in most instances can be installed at steeper slopes than the step-and-pool, and for a given height of obstruction, can be substantially shorter. They are very efficient at passing bedload materials which would block other types of fishways. However, baffles can easily catch floating debris, resulting in partial or complete blockage to fish passage. They require daily maintenance during fish migration season to ensure clear passage.~~



A	B	C	D	E
4'–0"	2'–4"	2'–0"	1'–0"	2'–8"
3'–6"	2'–0"	1'–9"	10.5"	2'–4"
3'–0"	1'–9"	1'–6"	9"	2'–0"
2'–6"	1'–5.5"	1'–3"	7.5"	1'–8"
2'–0"	1'–2"	1'–0"	6"	1'–4"

Figure VII-40. Denil fishway.

~~Alaskan Steep-pass~~

~~A modification of the Denil fishway, the Alaskan steep-pass, is smaller, reduces velocities more effectively, can be prefabricated from lightweight aluminum, and is easily installed (Figure VII-41). However, it is more likely to plug with debris.~~

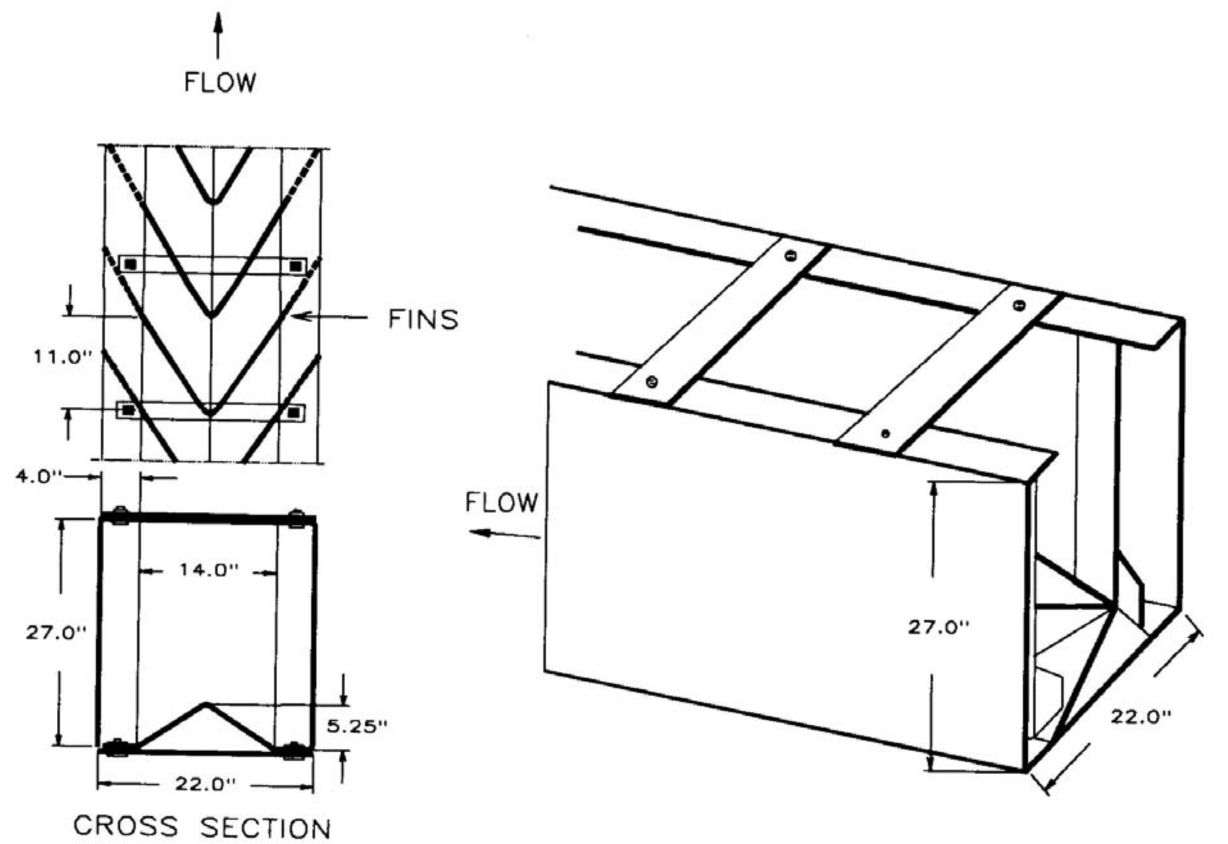


Figure VII-41. Alaskan steep-pass.

~~Placement of a fishway entrance is critical. The fishway entrance should be positioned where fish tend to congregate, normally in the area of greatest flow at the base of the obstruction. The bottom of the fishway must extend into the pool to provide a swim-in situation for the fish. Sometimes a rock wall, a training wall, or even a barrier dam, is needed to divert water and fish toward the fishway entrance. The Alaskan steep-pass has shown poor results in passing large salmon in California and is not recommended for that purpose. They have, however, proved efficient in passing steelhead.~~

~~Culverts~~

~~Properly installed culverts should pass fish during at least 90 percent of all anticipated flows. Migration barriers are frequently created by velocity chutes within culverts and jump barriers created by scour at the downstream end of culverts. Such barriers affect not only migrating adults, but they invariably prevent upstream juvenile movement during the low flows typical of summer rearing periods.~~

~~Back-Flooding Weirs~~

~~If the culvert is not installed with at least one-quarter of its diameter at or below the stream grade, the erosive hydraulic action of the discharged water will cut away the stream bed below the culvert outlet and create a waterfall. If this condition occurs, it can often be corrected by installing back-flooding weirs (Figure VII-42).~~

~~These weirs can be constructed of either logs or boulders. Ideally, the weir directly below the culvert should be of sufficient height to back-flood the culvert to a depth of 12 inches. Starting at the weir immediately below the culvert and proceeding downstream, each subsequent weir elevation should be no greater than a 12-inch drop (see section on boulder and log weirs).~~

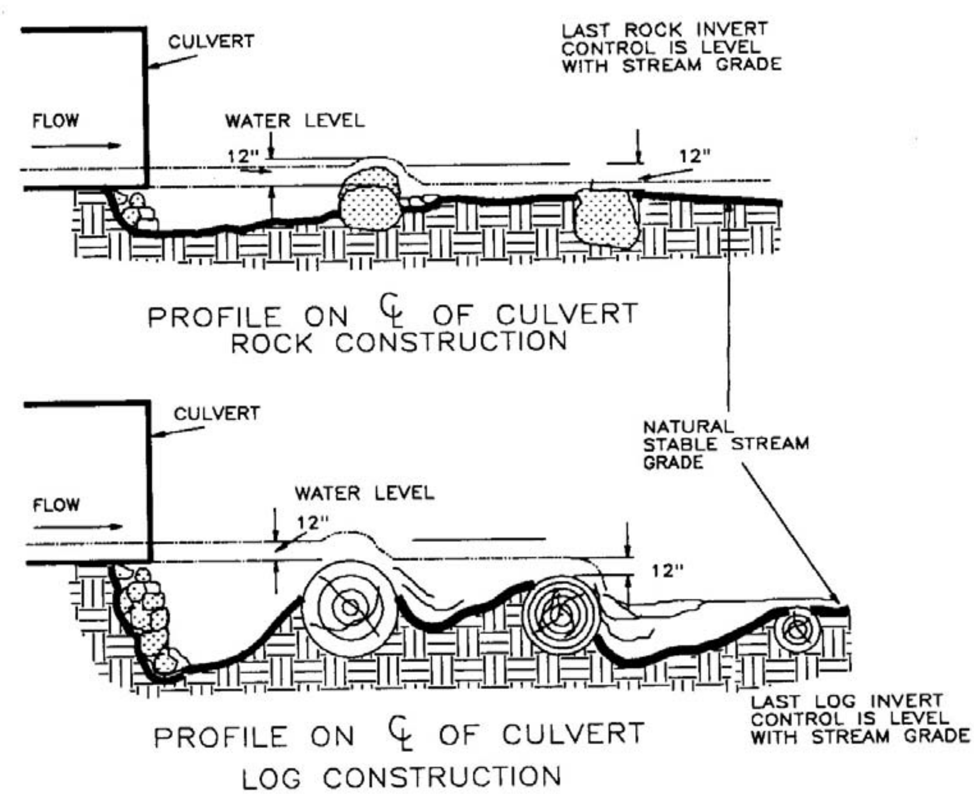


Figure VII-42. Back-flooding weirs.

~~Culvert Baffles~~

~~Culverts lack the natural roughness elements found in stream beds. Therefore, culverts often must be fitted with baffles to allow upstream fish migration. Installation of baffles in a culvert reduces the capacity of the culvert to pass water. It is important to calculate the discharge for the drainage area above the culvert to determine if the culvert will accommodate the expected discharge with baffles installed. The agency or landowner responsible for the culvert must be notified and be in agreement with the project before the baffle installation is begun. Two types of baffles are common in California: the Washington baffle, and the steel-ramp corrugated metal pipe baffle.~~

~~Washington Baffles~~

~~Washington baffles are designed to reduce velocities and increase water depths in concrete box culverts. These baffles should be constructed from either redwood or steel. In culverts exceeding 7 feet in width, a separator wall, two times the height of the baffles, should be installed to improve operating performance over a broad range of flows (Figure VII-43). To make the majority of flow go through the baffles during low flows, a flow barrier wall, half the height of the separator wall, should be constructed between the separator wall and the culvert wall. This will provide for low-flow passage of smolts and fry.~~

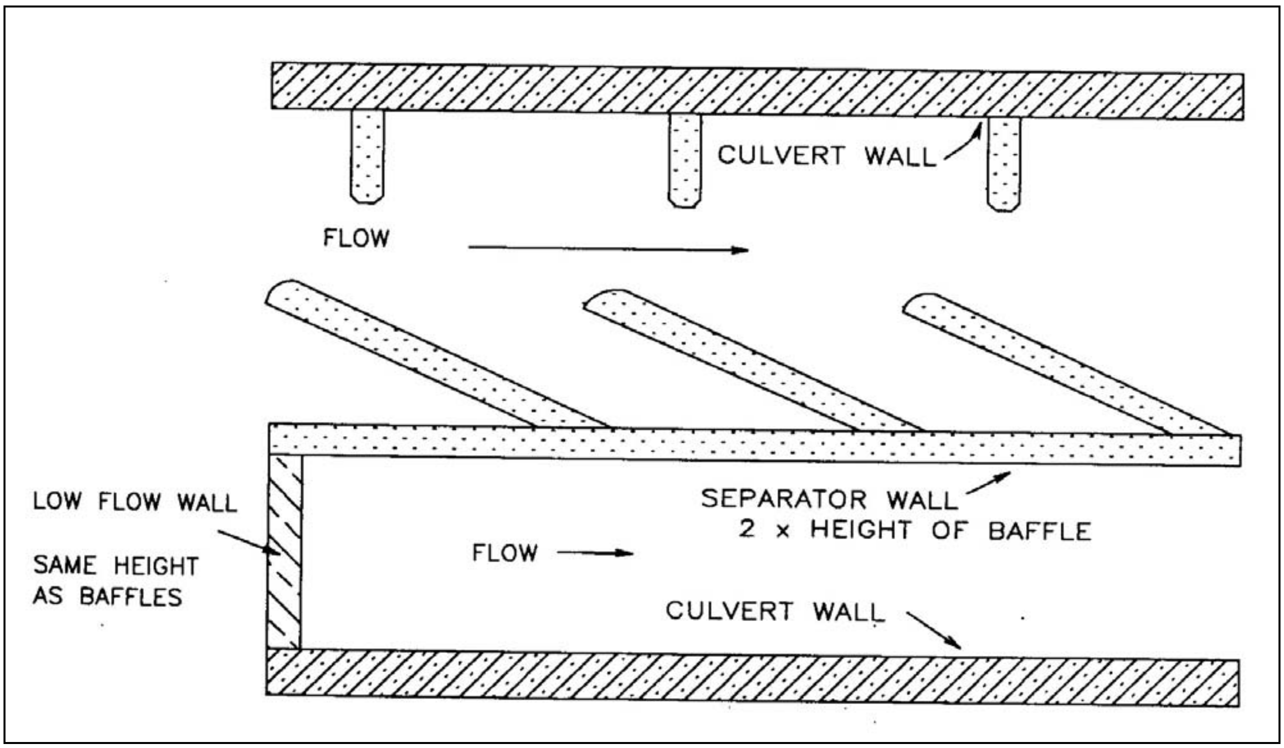


Figure VII-43. Washington baffles with a separator wall. (*Stream Enhancement Guide*, British Columbia Ministry of Environment, 1980, p. 42).

~~Baffles are installed with all long baffles on one side of the culvert, and all short baffles on the opposite side. Size of the baffle is determined relative to size of culvert. In box culverts less than 7 feet wide, length of the long baffle is 95 percent of the culvert width, and the length of the short baffle is 38 percent of the width of the culvert. The long baffle is oriented upstream 30 degrees from the culvert wall, and the short baffle is oriented 90 degrees from the culvert wall. Short baffles are positioned 26 percent of culvert width downstream from the leading edges of long baffles, facing the middle of the culvert. The first and last baffles in the culvert are spaced away from the ends a distance that equals 50 percent of the diameter of the culvert (Figure VII-44). Washington baffles must be placed in the thalweg. If the culvert is level, a low-flow training wall is needed at the head of the culvert to divert flows into the Washington baffles.~~

~~Redwood baffles are constructed from 6-inch by 6-inch redwood beams. This allows baffles to be installed easily in culverts with rough or cobbled bottoms because they can be cut to fit. Redwood baffles are secured to the culvert bottom with at least two 3/4-inch diameter, 18-inch-long threaded rods. Drill 7/8-inch holes, 6 inches deep in the culvert bottom, spaced 12 inches in from ends of the baffles. Secure threaded rods in holes with polyester resin adhesive. Drill holes in two 6-inch by 6-inch beams to match the spacing of the rods, forming a baffle 12 inches high. The upper beam must have a countersink hole drilled in the top side to allow recessing the washer and nut on the anchor bolt (Figure VII-45).~~

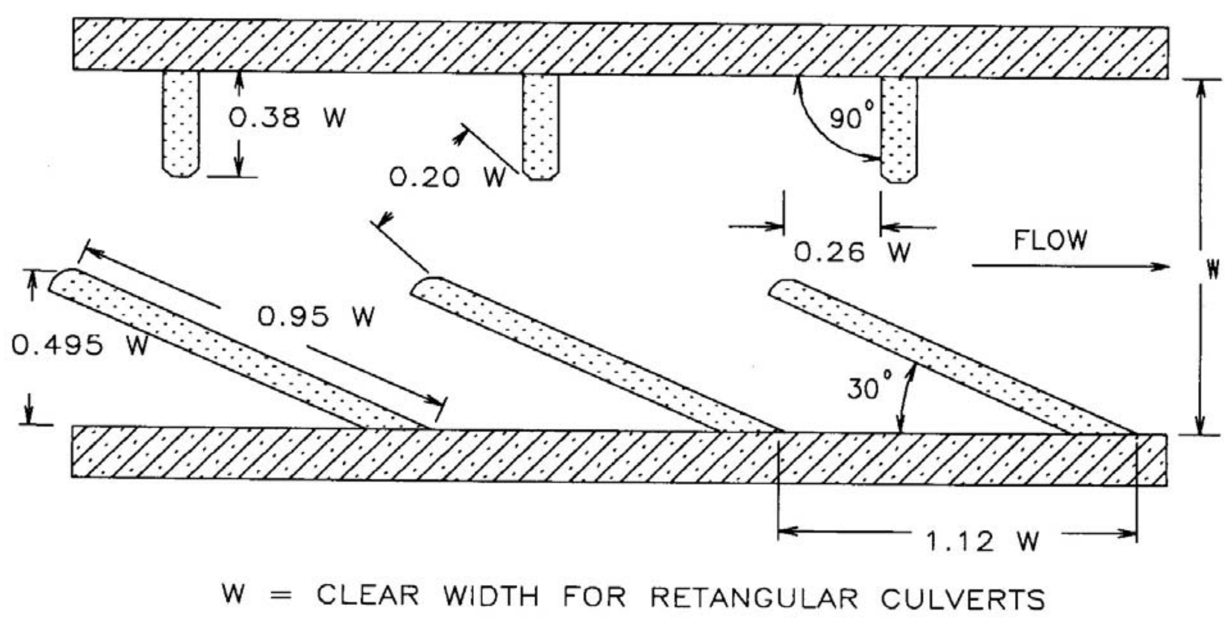


Figure VII-44. Washington baffles. (*Stream Enhancement Guide*, British Columbia Ministry of Environment, 1980, p.42).

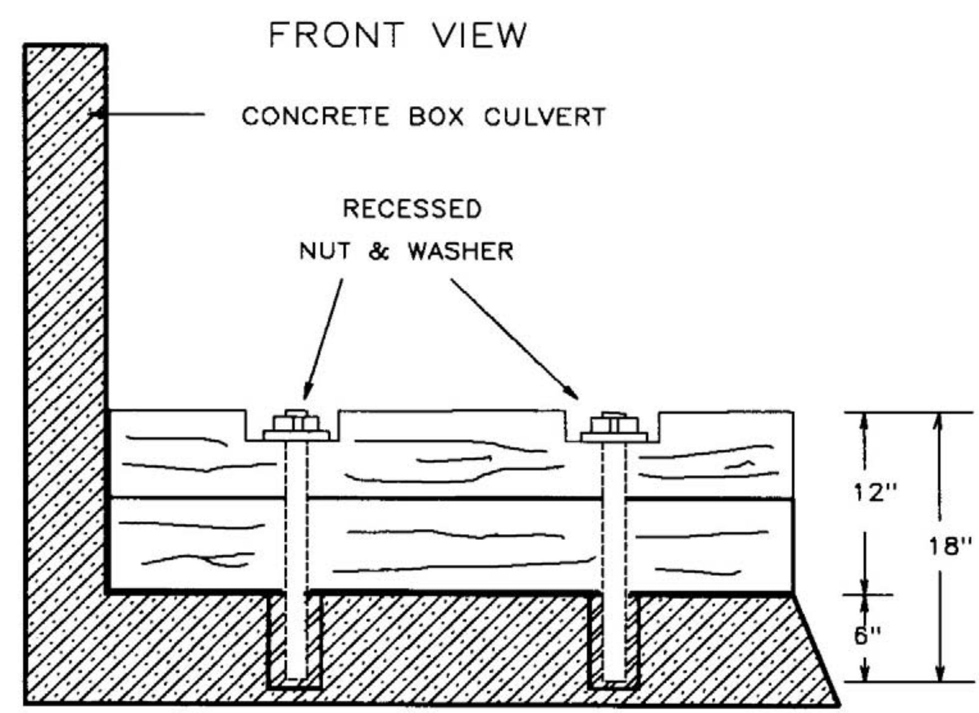


Figure VII-45. Redwood Washington baffle construction.

~~Steel Washington baffles are more resistant to bedload abrasion than wooden baffles (Figure VII-46). Steel Washington baffles are installed in the same manner as redwood Washington baffles with the following exceptions. Baffles are secured to the culvert bottom with 2-inch square mounting tabs, welded front and back. Each tab is drilled with a 3/4-inch bolt hole. Long baffles have four and short baffles have three tabs on each side. Drill 7/8-inch holes in the floor of the concrete culvert 6 inches deep to match the hole pattern on the baffles. Secure 7-inch X 3/4-inch threaded rods into the holes with polyester resin adhesive. Place the baffles over the rods and secure them with washers and nuts. The baffles may also be installed using expansion bolts.~~

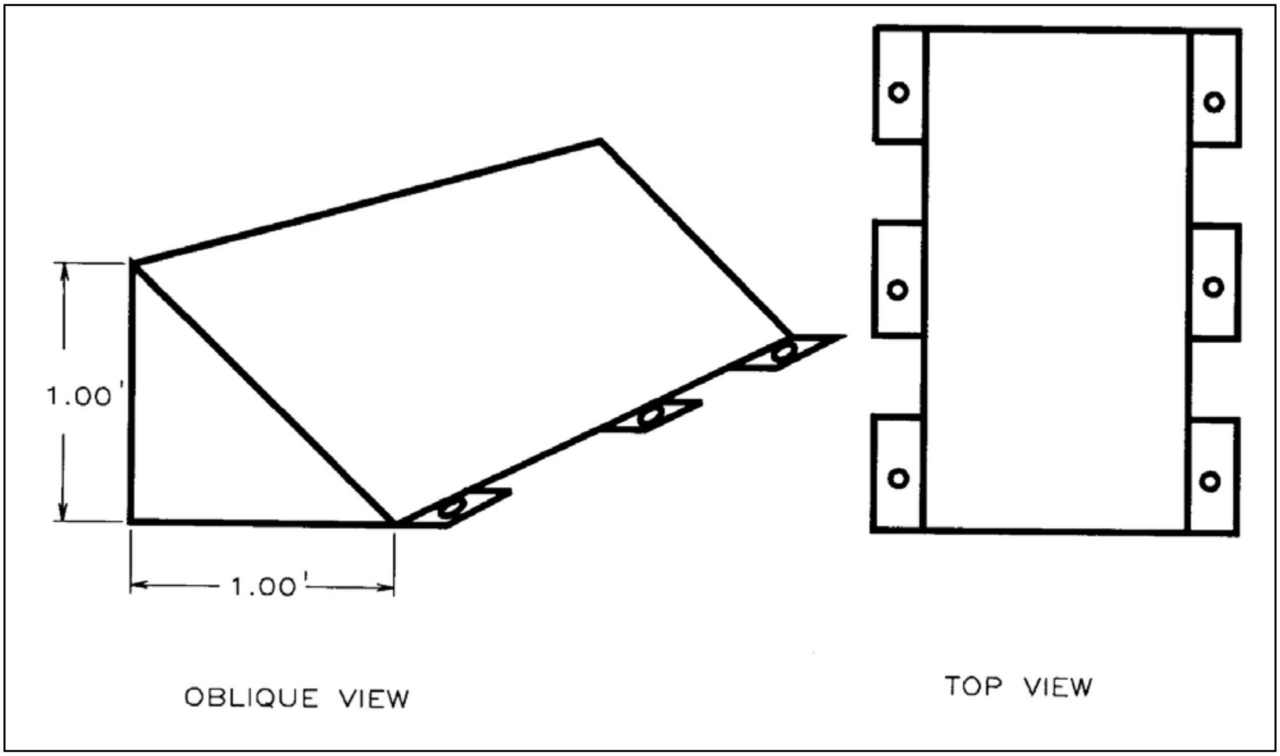


Figure VII-46. Steel Washington baffle.

~~Corrugated Metal Pipe (CMP) Steel Ramp Baffles~~

~~CMP steel ramp baffles are used in corrugated metal pipe where Washington baffles are difficult to install because of the curvature of the culvert. The narrow width of steel-ramp baffles allows them to be installed easily on the curved bottom of CMP culverts without leaving a gap under the baffle. Baffles should be attached to CMP culverts by welding, or with "L" bolts if the bottom of the culvert is in good condition (Figure VII-47).~~

~~Steel ramp baffles are installed alternating from side-to-side along the center line of the culvert bottom, with the ramp face of the baffle oriented upstream. They are spaced apart a distance equal to approximately 90 to 95 percent of the culvert diameter. Minimum thickness of the baffle material should be 1/4-inch steel plate. Baffles can be constructed to fit varying sizes of culverts. In culverts 6 feet in diameter and larger, 24-inch wide baffles are used. In culverts 4 feet in diameter, 16-inch-wide baffles are used. In culverts 3 feet in diameter, 12-inch-wide baffles are used. All baffles have 12-inch-high faces.~~

~~If baffles are bolted into the culvert, weld two tabs perpendicular to the bottom edge of the baffle's vertical side. Drill 3/4-inch holes in the leading edge of the baffle and in the tabs. The distance between the front and back holes must be matched to the distance between convex ridges in the corrugated pipe where the 3/4 inch "L" bolts are to be secured. Mark and drill the holes in the culvert bottom using the baffle as a template.~~

~~The "L" end of the anchor bolts are placed in the holes drilled in the culvert bottom. Baffle is then placed over the anchor bolts and secured with washers and nuts.~~

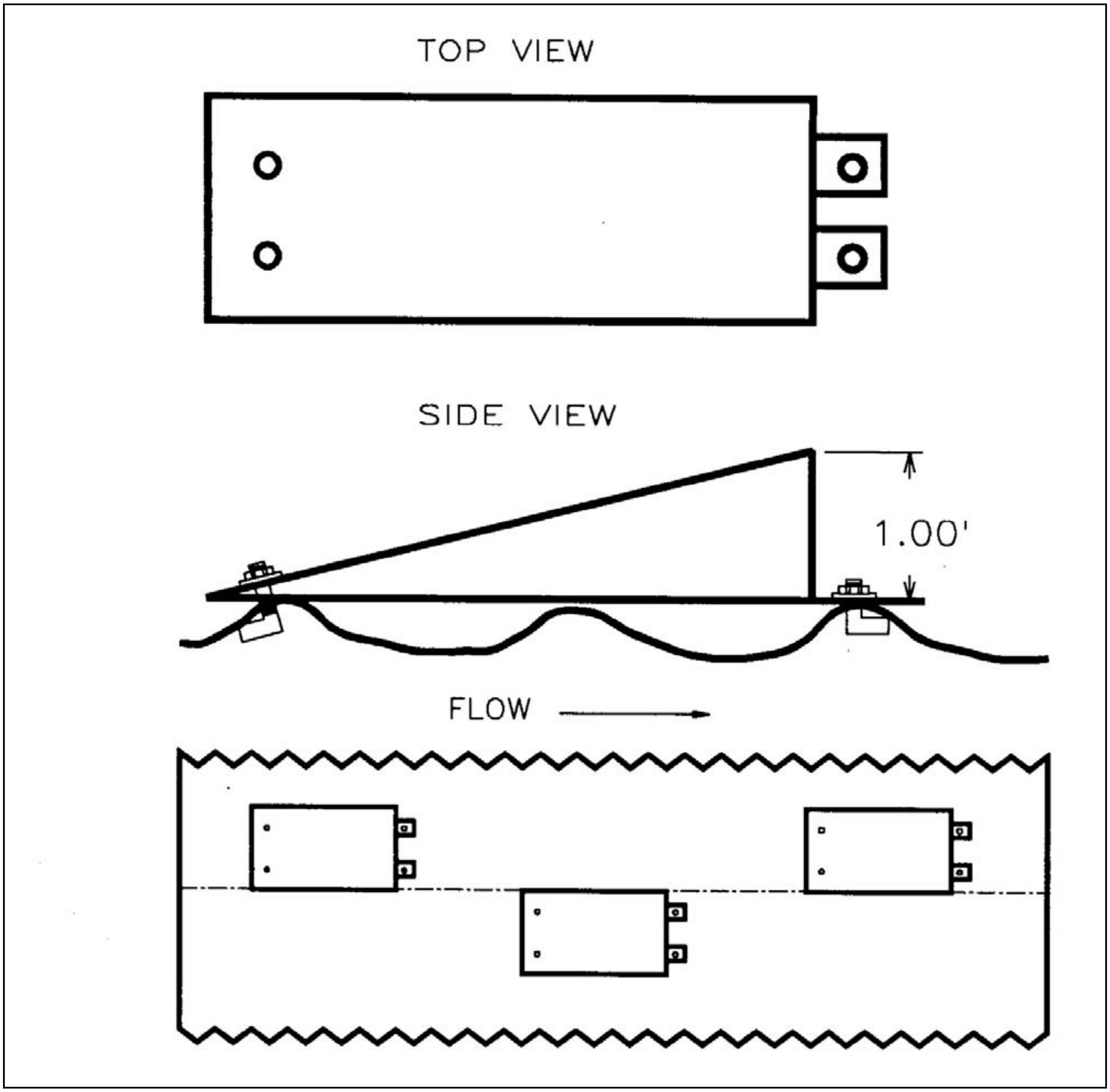


Figure VII-47. Corrugated metal pipe steel ramp baffles.

WATERSHED AND STREAM BANK STABILITY

Many streams are seriously affected by sediment from watershed and stream bank erosion. In all watersheds, erosion occurs in major storms. Other events occasionally occur which result in massive slope failure along a stream. These failures often introduce large amounts of fine sediment. However, they may also be a vital source of gravel, cobble, boulders, and large woody debris. Effects of each slope failure must be evaluated accordingly. Fine sediment may have a negative effect on fish habitat by covering spawning gravel, filling in pools, and creating high turbidity levels, which may cause gill abrasion, disease, stress, and egg or fish mortality. In some cases, these problems might be relatively short-term, especially when balanced against habitat benefits created by introduction of large, stable, structural elements.

When assessing erosion in watersheds, massive slope failures usually draw a great deal of attention but there are many other erosion sources that contribute fine sediment to streams. These are usually more easily treated than massive slope failure. This section will focus on: 1) landslide stabilization; 2) stream bank stabilization; 3) upslope erosion control with mulching; 4) revegetation in the riparian zone and upslope; 5) checkdam construction to control gully erosion; 6) waterbar construction to control erosion from dirt and gravel roads; and 7) exclusionary livestock fencing.

Slide Stabilization

Slide stabilization requires use of one or more complementary methods to control the slide toe, protect the slope surface, and treat the head and seat of the mobilized area of the slope. Mass slope failure can take many forms. These include slumps, rotational movements of "blocks" of soil, soil or mud flows, debris torrents, and slope creep. Slides are areas where the surface layer of soil and its accompanying vegetation move downhill under the influence of gravity. Slides are usually triggered by undercutting, or some force like heavy rain or earth tremors. Excess water that adds weight or liquidity to the slope may accumulate due to a heavy rainfall or snow melt, vegetation removal, or disruption of the natural drainage pattern.

Sometimes, dried out soil can result in a slide because the bonding of water molecules provided by moderate soil moisture is lost. This can happen if vegetation has been removed and the slope has lost its shade cover and the binding properties of roots.

The cause of a mass slope failure must be determined before an appropriate treatment can be prescribed. This may require an air photo analysis (historical sequence), geological and topographic map review, hydrological investigation, and field surveys to verify map and photo analysis (Part II). Once background information has been obtained and verified by field surveys, decisions on treatments can be made.

Slide stabilization is employed only where it is determined to be beneficial and feasible in reducing the amount of fine sediments entering the stream. Slides may best be stabilized and sediment input to streams reduced by a combination of toe protection, upslope drainage correction, and revegetation techniques.

Stream Bank Stabilization

Stream bank erosion is a natural process that can be beneficial by providing a source of boulders, cobble and gravel for fish habitat. However, when natural levels of erosion are exceeded, fish habitat balance may be lost and the stream and riparian zone may have difficulty recovering. In these situations, it is desirable to stabilize eroding stream banks. This can be accomplished with boulder and log structures, revegetation, and removal or relocation of obstructions that are deflecting flow into unstable banks. If there are relatively few isolated bank erosion problems, it is probably feasible to armor the eroding banks. However, when there are numerous landslides and bank failures along a channel, it may not be cost effective to undertake spot treatment. If the basic destabilizing process in a watershed, such as altered runoff rates, can not be controlled, treatment may not have a reasonable chance of success.

In some situations, stabilization of eroding banks may be detrimental to fish habitat. For example, on some levees built for flood or erosion control, development of riparian vegetation is prevented by manual or chemical means. In fisheries applications, bank stabilization must address the objective of improving fish habitat.

Access to an erosion site and availability of materials will partially determine the stabilization procedure, while stream hydrology and channel type will dictate the structure used. Hydraulic cross-sectional analysis will disclose stream dimensions required to assure passage of bankfull flows.

Boulder Stream Bank Stabilization Structures

Boulder structures are the preferred method for stabilizing stream banks because of their longevity and resistance to movement. Boulders can be used to riprap stream banks or construct wing-deflectors to deflect flow away from an unstable bank.

Boulder Riprap

Boulder riprap is a method for armoring stream banks with large boulders for preventing bank erosion. Riprap footing is laid in a "toe" trench dug along the base of the unstable bank. Boulder riprap is then laid on the bank slope up to the bankfull discharge level. Large angular boulders are best suited for this purpose. The exact size of boulder will vary with size of the channel and the stream. Revegetation with native species, including coniferous and deciduous trees, shrubs, and ground cover should be included as part of the treatment.

Boulder riprap can provide toe protection to a slide or other stream bank instability. It can be very useful for protecting banks in areas where log or boulder instream structures added to the stream could lead to stream bank erosion.

The type of boulder selected will be a major determinant of stability and longevity of the riprap. If boulders are imported, large, dense, angular boulders are preferable. It is important that only structurally competent boulders be used. Some kinds of boulders will break down rapidly and should be avoided, such as sandstone or some other types of sedimentary rock, which are poorly bonded and deteriorate rapidly.

The toe trench must be excavated to sufficient depth to prevent the structure from becoming undermined. If there is equipment access, this can be most effectively accomplished with a backhoe or excavator. Excavators work well on large streams that require relatively large rock. In smaller systems a backhoe can perform equally as well, is much faster to move, has the advantage of a front-end loading bucket, and is less expensive. Regardless of the machine in use, the key is to have an experienced, competent operator who is sensitive to the stream environment.

An excavator or backhoe can also be used to place boulders. Many machines have a bucket equipped with a thumb which makes it possible for them to grab boulders. These machines are ideal for setting riprap boulders. A front-end loader or bulldozer working in conjunction with a backhoe or excavator can greatly facilitate the construction process.

A toe trench that provides solid footing for riprap layers is necessary to prevent stream flow from undermining the riprap and causing it to collapse into the channel. Collapsed riprap could cause even more severe bank erosion. Riprap should not be attempted in streams with degrading streambeds. As the streambed degrades, riprap will be undercut and fail.

The largest boulders are placed in the toe trench to create the footing. They are placed tightly against each other. The next layer of boulders is placed so that it tapers back slightly from the base layer toward the near stream bank. The most stable riprap slope construction is achieved when each boulder has contact with at least three others, (three point contact). It first may be necessary to contour the bank above the channel, especially if it is vertical or nearly vertical. Slope should be no more than 1:1 or 45 degrees (the lower the angle of slope, the more stable it will be). Ideally, the finished angle of the riprap will be 2:1. The biggest boulders should be used in the lower layers and the smaller ones placed in the upper layers (Figure VII-48). Riprap should extend to above bankfull discharge. Riprap should also extend a little upstream and downstream from the treatment site to assure that the stream does not erode at the edges of the riprap. Riprap will resist erosion and may accelerate stream flow, creating a new erosion hazard downstream. It is essential that the banks at the end of the riprap are stable and resistant to erosion and that precautions are taken to avoid downstream damage.

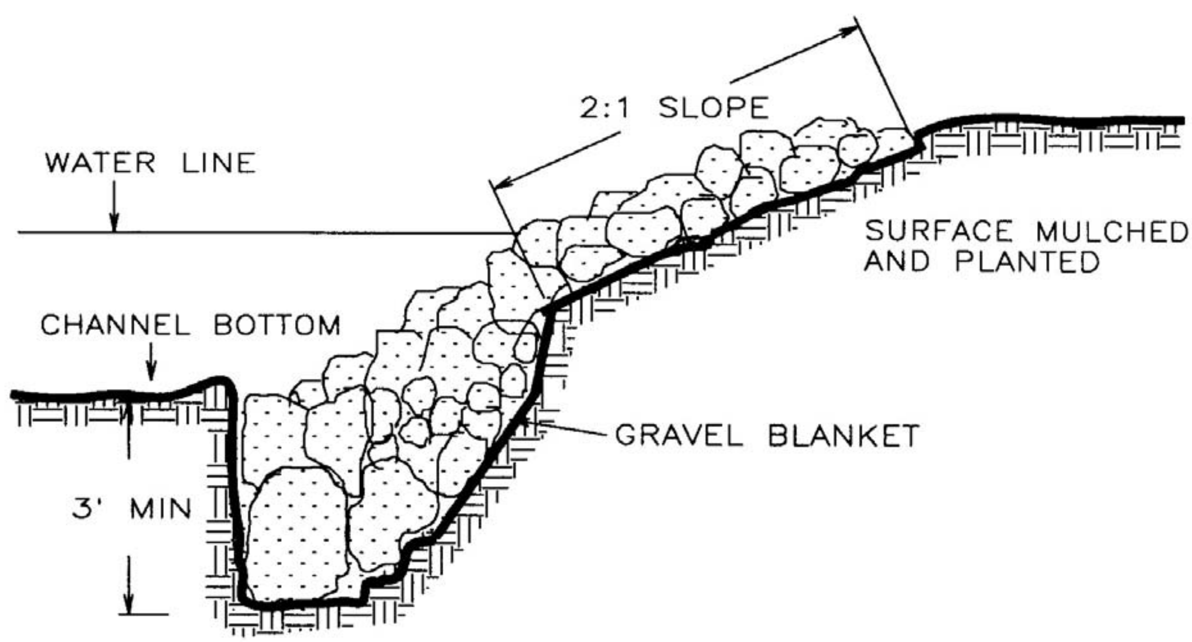


Figure VII-48. Riprap.

A gravel blanket or geotextile fabric should be used under riprap. In general, geotextile fabric is used on slopes which are 3/4 to 1 or less, simply because gravel will not stay on these slopes. A gravel blanket that is one foot thick should be used on slopes of 1:1 or greater. The purpose of the gravel blanket or geotextile fabric is to prevent soil underlying the placed riprap boulders from washing out and possibly causing the riprap to slump and fail. Use of geotextile fabric inhibits establishment and natural spread of plants on treated sites. Woody cuttings can be punched down through geotextile fabric, but other plants cannot push roots down through the material. Never install geotextile fabric where a gravel blanket can be used effectively.

It may be necessary to chink riprap interstices with small rock if bank material is particularly erosion prone. This protects underlying material from exposure to high-velocity flows.

Boulder Wing-Deflectors

Wing-deflectors used for bank stabilization are similar in construction to wing-deflectors used to create or enhance specific fish habitat features. In most cases, bank stabilization and habitat restoration benefits can be achieved. Wing-deflectors installed solely to provide bank stabilization may have a higher angle of intersection with the stream bank.

Wing-deflectors direct flow away from an unstable bank and provide armor (a hard point) to protect the toe of the slope from further erosion. Improper use of wing-deflectors can cause accelerated erosion on the opposing bank. Boulder faces in the deflector structures have the added benefit of providing invertebrate habitat, and space between boulders provides juvenile salmonid escape cover (Figure VII-49).

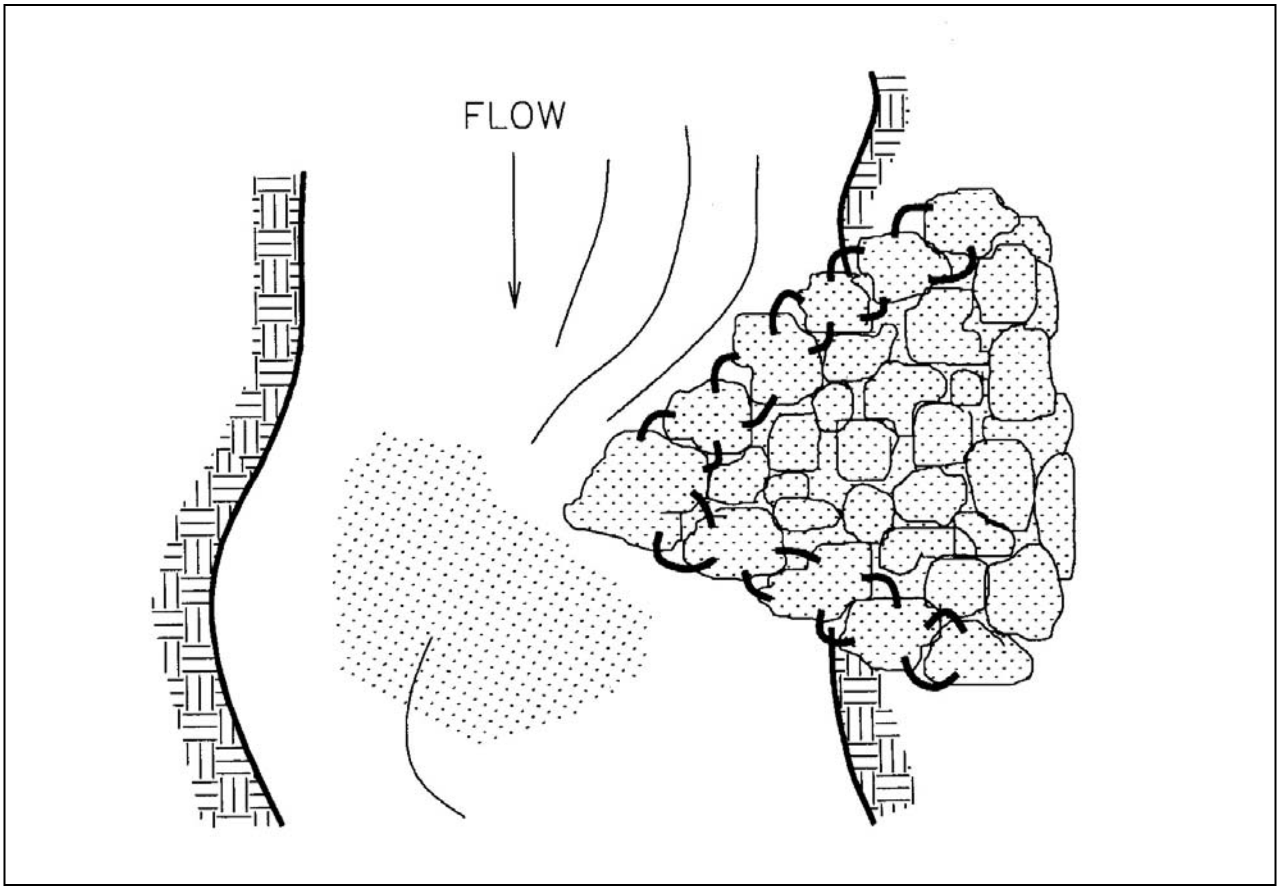


Figure VII-49. Boulder wing-deflector.

Depending on flow regime of the stream and size of the boulders used, it may be necessary to cable boulders together using polyester resin adhesive. The largest boulder(s) available is used for the apex of the deflector. The apex of the deflector is at the lowest elevation. The deflector should slope upwards to the bank. Rate of rise will be determined by bank conditions. This angle should be no more than 45 degrees. Additional layers of boulders may be placed on top of the base layer to reach the desired elevation and slope angle. If the substrate allows, a toe trench should be dug for the upstream and downstream legs of the deflector, and the structure must be keyed at least 4 to 6 feet into the stream bank.

The leading, or upstream edge of the deflector should be the longest side of the structure and should form an angle of approximately 30 degrees with the bank. The leading edge on the upstream side of the deflector should contain the largest available boulders. The downstream edge should be made with the remaining largest boulders. The interior of the triangle can be filled with smaller boulders. Depending on bank conditions upstream and downstream of the deflector, bank armor may be required adjacent to the wing-deflector.

Log Stream Bank Stabilization Structures

Log structures can be used where there is no access for heavy equipment, logs are available, and boulders are scarce. Log structures are generally not as durable as boulder structures. Banks can be further stabilized by planting vegetation, such as willows and cottonwoods, behind a log structure.

Cribbing

Cribbing construction is similar to building a log cabin. Logs are notched and cross logs are inserted between the layers and extended back into the bank. Cribbing protects the stream bank from high flows and holds soil in place (Figure VII-50).

Cribbing is used to reduce sediment input to a stream where bank erosion is a problem, logs are available, heavy equipment access is lacking or boulders are not available. Crib construction is labor intensive, but material costs are relatively low. If not available on site, suitable logs for cribbing must be located and delivered to the site. Logs should be selected for soundness, durability, uniformity of size, and ease of handling and delivery.

A base log(s) is placed in a toe trench below stream grade to prevent undercutting the structure. Base log(s) should be as long as can be manipulated while conforming to the contour of the stream bank. A good base log is necessary to insure stability and durability of the treatment.

Tieback logs are notched into the base log and placed at intervals along the base log (usually every 6 to 8 feet). Tieback logs are imbedded into the slope four to six feet, at grade with the base log. There should be at least two tiebacks per base log. Tiebacks are secured to the base log using threaded rebar. Approximately halfway up the backside of the base log, geotextile fabric is stapled every six inches, and placed to seal the bedding for the structure.

Once the first row of logs has had tiebacks and geotextile fabric installed, and has been back-filled to the top of the log, a second face log is placed on top of the tiebacks. This log is set back approximately 6 inches. The same procedure is repeated until desired height is reached. Stacked face-logs used in cribbing must be secured together using threaded rebar and/or cable. If cable is used to secure face logs together, the cable must be tightened using a fence stretcher or power pull. Finished height should reach the bankfull discharge level.

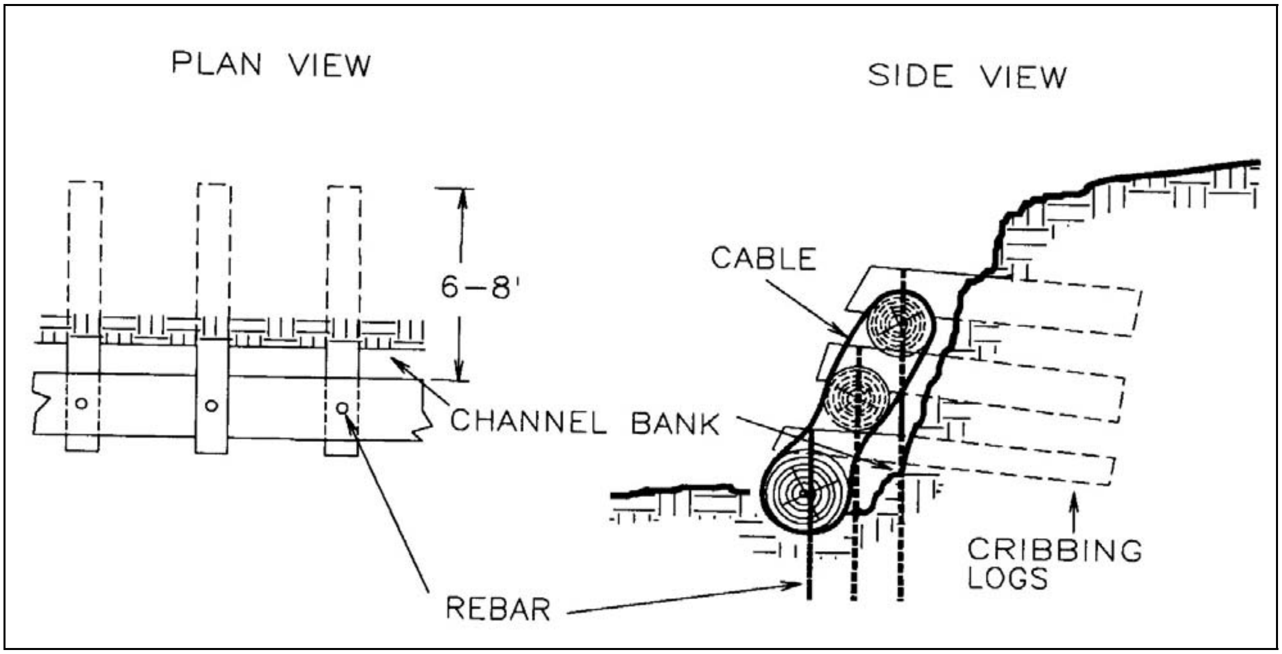


Figure VII-50. Log cribbing.

Live Vegetated Crib Wall

The basic construction of live vegetated crib walls on stream banks is the same as standard log crib walls. They may be built as either single or double walled structures. The double wall crib has far greater resistance to high flows (Figure VII-51). As each lift of the crib wall is installed, long cuttings of riparian plants are inserted on top of each fill layer. Willow can be used in combination with other fast rooting brush species such as native blackberry. The live willow cuttings function to replace crib logs as they decay over time. These riparian plants grow very rapidly and provide stream shade canopy and wildlife habitat during their first growing season.

1) As each lift is constructed, the face logs and tiebacks are filled with a mix of gravel and cobbles to the top of the face log. It is not necessary to use topsoil in the fill material, however, there should be enough fine grained materials to insure vegetation growth.

2) Live cuttings are laid in to form a complete cover layer. These live branches should have their butt ends into the soil behind the crib wall. The tips should stick out from the wall no more than one quarter of the cuttings total length.

3) The branches are then covered with a gravel/cobble mix to the top of the tiebacks.

4) Continue the next layer of the crib wall to the desired height.

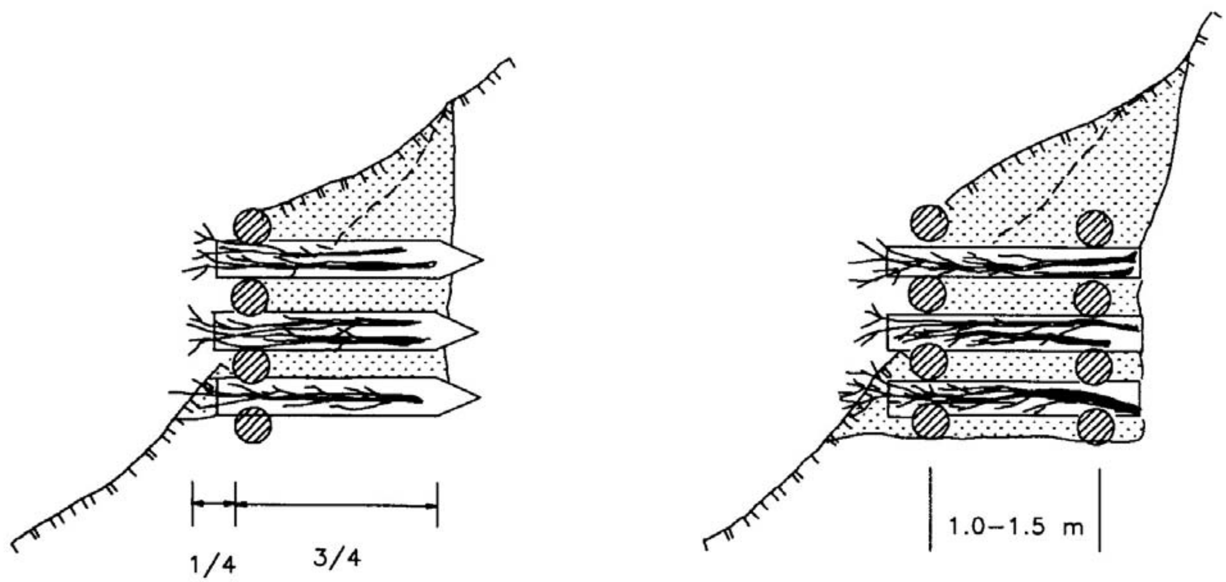


Figure VII-51. Live Vegetated Crib Wall (Schiechtl and Stern, 1996)

Bank Armor

Log bank armoring is accomplished by stacking logs against the stream bank, parallel to the stream flow, to protect the bank against erosion. The log or logs are held in place by cabling them to boulders, heavyweight metal fence posts, culvert stakes, or a deadman (Figure VII-52).

By protecting the toe of unstable stream side slopes, erosion of fine sediment can be reduced and the stream bank can be stabilized. Logs can be used for stream bank armor in combination with other instream structures that require bank protection.

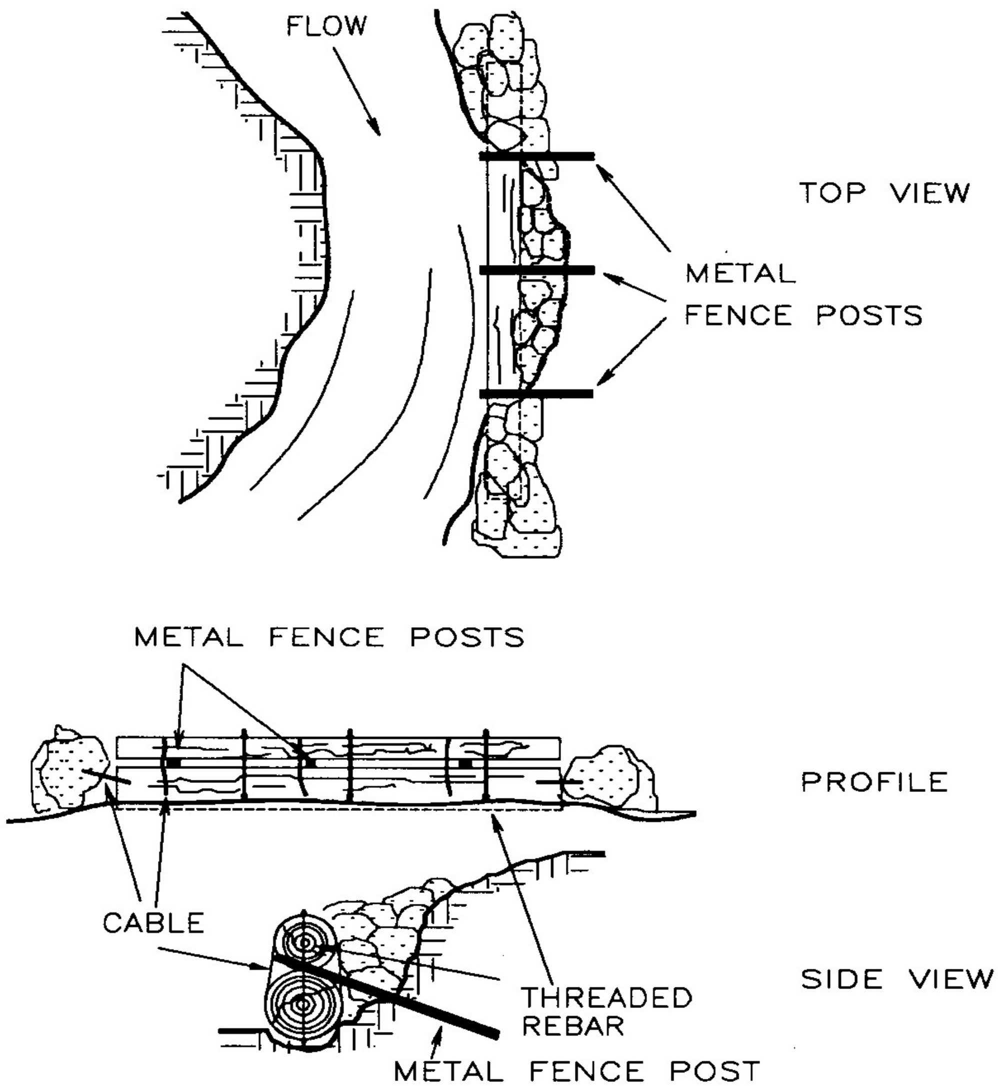


Figure VII-52. Log bank armor.

Bank armoring with logs requires excavation of a toe trench to accommodate a base log. The trench is dug along the base of the bank to be protected. Approximately one-third to one half-of the base log should be buried in the trench.

Once the toe trench is excavated, the log can be placed. If the angle of the bank behind the log is steep, a second log can be placed above the base log. This log should rest partly on the base log and partly on the stream bank. Finished height of the bank armor should be the elevation of bankfull discharge. If bank armor is needed to protect an unstable stream bank, it may be necessary to install cribbing instead of armor.

Large boulders can be used to secure the ends of the logs. If boulders are not available, smaller rocks can be stacked on the log and cabled together. Cable should be run through a drilled hole in the log and into a hole in the boulder anchor. If boulder anchors cannot be acquired, heavyweight fence posts or culvert stakes can be used. Stakes are placed on both sides of the log at about 6-foot intervals. Stake sets should be placed at both ends of each log. Spacing and length of stakes will vary depending on size of the log and magnitude of bankfull discharge. Stakes should be twice the length of log diameter and should be driven in so they do not protrude above the top of the log. With large diameter logs the force of buoyancy during high flow events will exert great pressure on stakes and the greater the number of stakes anchoring the log, the greater the chances of avoiding structure failure.

Cable can be attached to culvert stakes by drilling through the stake, running the cable through the hole, and clamping the cable back to itself. Flexible, small-diameter cable, from 3/8-inch to 1/2-inch should be used. When using regular metal fence stakes, drilling a hole large enough to pass the cable may not be possible. The cable must be looped tightly around the stake, using two wraps to make it secure, and clamped so that the loop will be held by the knobs of the fence stake. Fence stakes should be driven in at an angle over the top of the log (Figure VII-52). This will keep the cable from slipping over the top of the stake. Once the cable is securely attached, the stake should be driven in to tighten the cable over the top of the log.

Another way to hold the log in place is to use cable attached to a deadman placed in the bank. Unless a deadman is placed lower than the top of the uppermost log and secured with a tight length of cable, the log will be able to rise with the water level in high flows and may actually cause stream bank scour. In almost any situation, it is very difficult to prevent the log from floating during high flows if a deadman is the only anchoring system used. The deadman anchors should be placed at the same intervals as stakes, every 6 to 8 feet.

To add to stability of the log armor and to prevent fine sediment from eroding beneath it, staple geotextile fabric and fencing to the backside of the logs. Log structures should then be back-filled with cobble or boulders. As with any bank stabilization technique, woody vegetation should be planted behind finished log armor.

Log Wing-Deflectors

Log wing-deflectors are used to direct flow away from an unstable bank and hold soil on the bank. The deflector usually incorporates boulders to fill the interior of the triangle and to anchor the logs. The boulders add stability to the structure (Figure VII-53).

When used for stream bank stability, deflectors are almost always installed on the scoured bank only. Wing-deflectors may be installed in series. Wing-deflectors used for bank protection are the same general design as deflectors used for stream channel improvement. Site-specific alterations are made depending on size and extent of bank protection needed and the angle of bank slopes.

Wing-deflectors installed for stabilizing stream banks require placement of rock or other armor to a height above bankfull discharge level, to assure that the bank is adequately protected under high flow conditions. A series of wing-deflectors can be made to protect a length of stream bank beyond the length that can be protected by a single deflector.

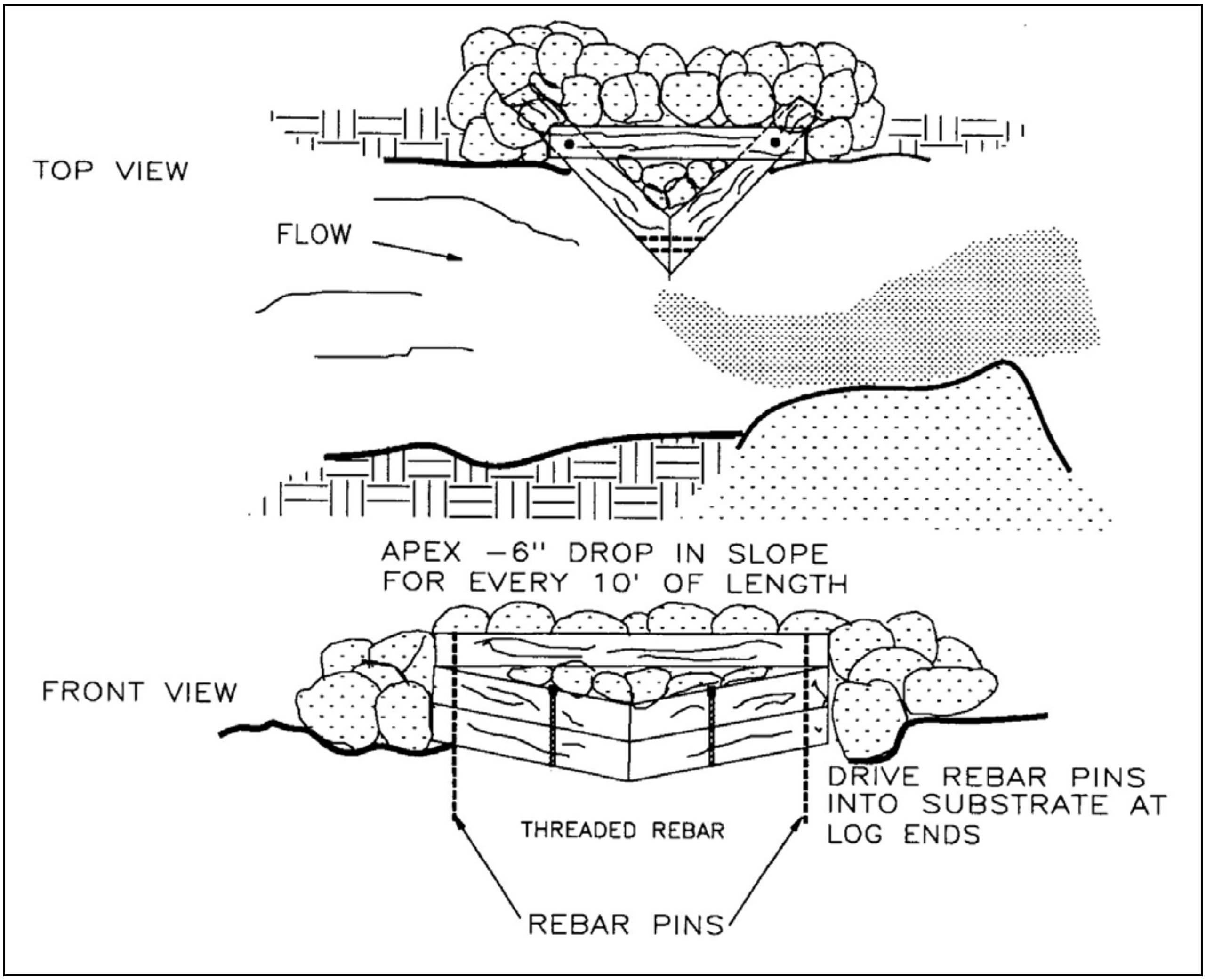


Figure VII-53. Log wing-deflector.

Tree Revetment

Tree revetment is used to stabilize vertical, eroding stream banks in low gradient meadow type streams. Trees are cut and laid against the vertical bank with tops angling downstream. Butts are tied off to the upper stream bank. Branches slow the water velocity and cause suspended sediment to settle, allowing bank building and revegetation to begin (Figure VII-54).

Cedar, Pacific yew, and juniper are preferred tree species, but almost any pre-commercial size conifer will suffice. Alders are not desirable due to their rapid decomposition. Care must be taken that water quality problems are not created in areas of low flow or standing water. Riparian vegetation generally should not be sacrificed for building material.

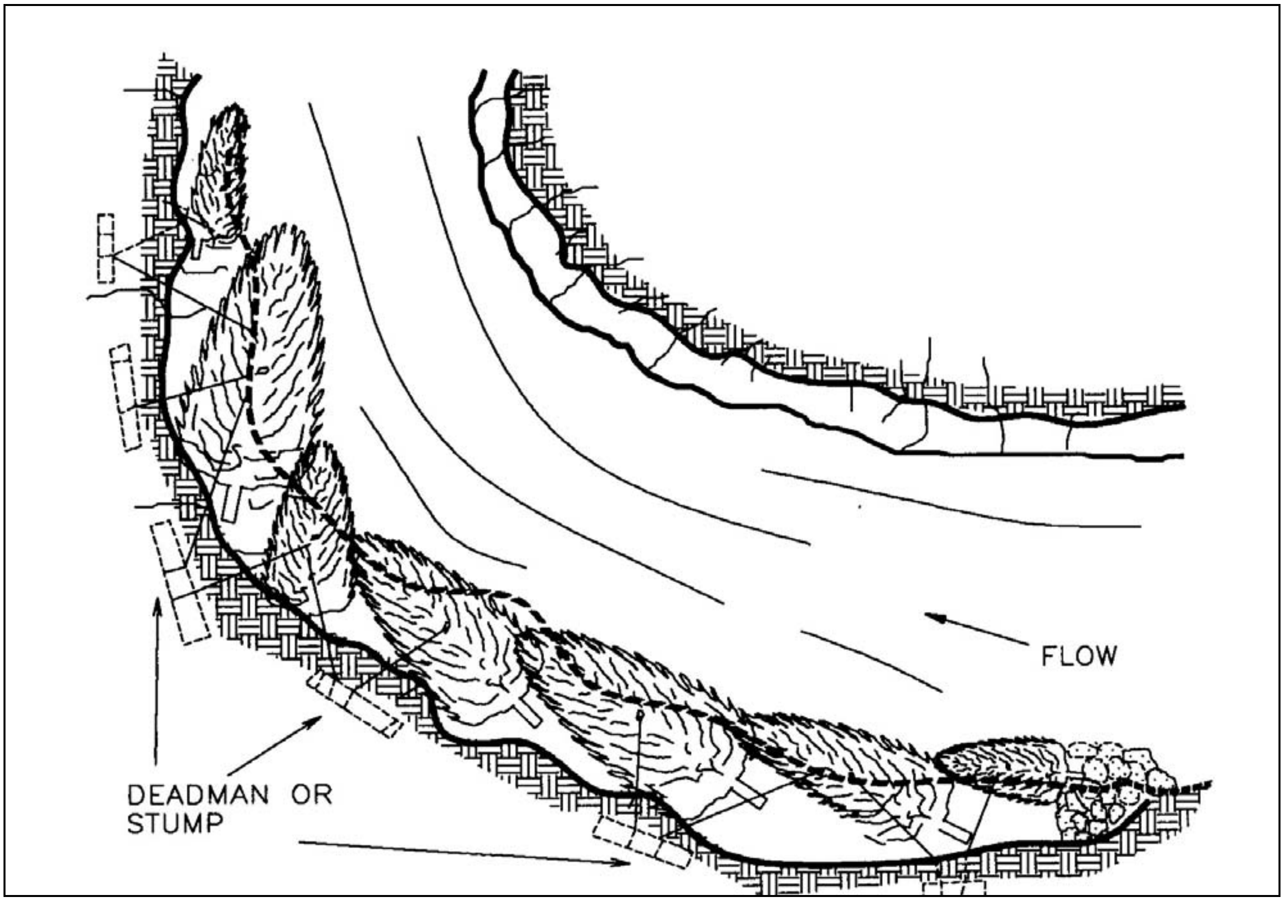


Figure VII-54. Tree revetment.

Native Material Revetment

Native material revetments are alternatives to boulder riprap armoring and crib wall type structures. By combining boulders, logs, and live plant material to armor a stream bank fish habitat is enhanced, in addition to creating a natural looking bank stabilization structure. Native material revetments can provide toe protection for slides or eroding banks and can also be used to re-establish natural stream channel dimensions (Figure VII-55).

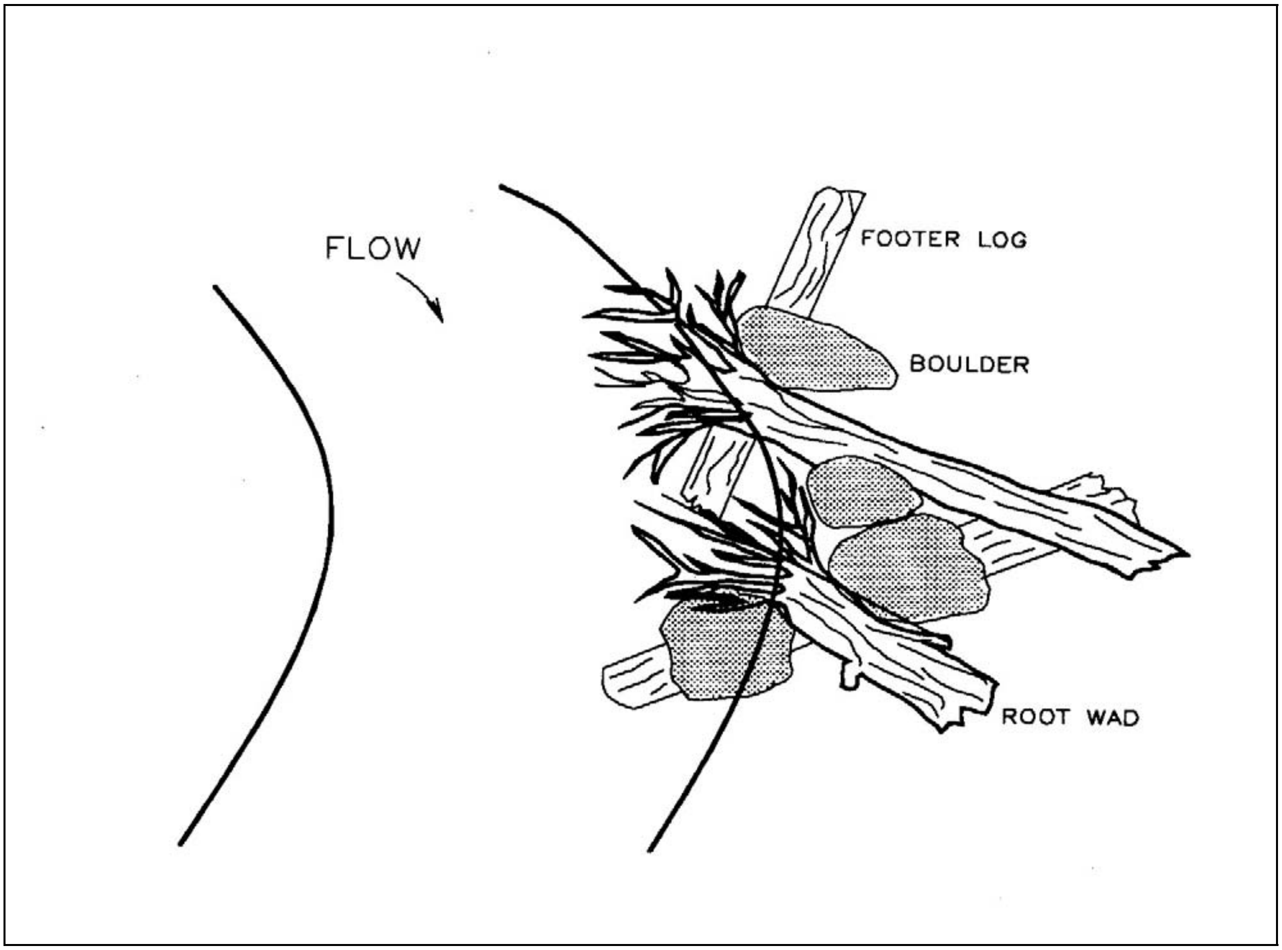


Figure VII-55. Plan view of native material revetment (Rosgen, 1993)

A backhoe or excavator are essential in construction of the revetment. The material sizes needed will vary depending on the stream size and hydrological factors. Logs, preferably redwood with root wads attached, boulders and live plant materials are placed in sequence to ensure stability and proper function of the structure.

Logs without root wads (footer logs) are set in a toe trench below the thalweg line, with the channel end pointed downstream and the butt end angled 45 to 60 degrees upstream. A second log with a root wad is set on top of the footer log diagonally, forming an "X." The root wad end is set pointing upstream and the butt end lying downstream 45 to 60 degrees. The apex of the logs are anchored with threaded rebar. Large boulders are secured in the spaces between the logs, at each apex. After all the logs and boulders have been set in place, any live plant material disturbed from the site along with recruited willows are placed within the spaces of the structure, behind the boulders. Once this has been done the excavated gravel and streambed materials can be placed over the bank-end portion of the revetment (Figure VII-56).

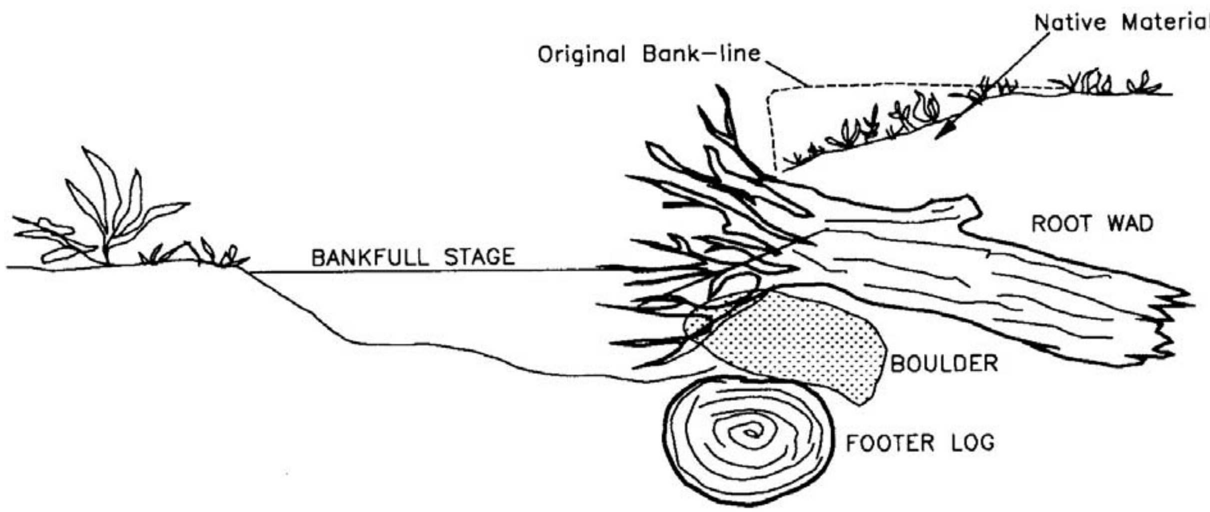


Figure VII-56. Native material revetment (Rosgen, 1993).

Mulching

Mulching for erosion control is covering soil with straw or similar material to discourage erosion and encourage revegetation. It is principally used to protect bare soil from rain and sheet erosion. In areas of heavy rainfall, erosion caused by raindrop impact can be significant. Mulching will also shade soil from the sun and prevent soil from drying. This assists in re-establishing vegetation by creating a stable seed bed and keeping soil moisture levels from becoming too low to sustain new vegetation.

Mulching can be accomplished by adding straw or forest leaf litter to bare soil. Other mulches can be used, but unwanted or exotic plant species may be introduced with them. Such plants can depress native vegetation and become established as a nuisance species. Leaf litter from the forest may be available for the cost of labor to collect it and will usually not contain seeds of undesirable species. Leaf mulches may have to be secured with jute netting. If it is necessary to buy and transport mulch, straw is the most economical and convenient but may contain seeds of undesirable plants. Straw mulch should be applied at the rate of two to three tons per acre. This results in a mulch coverage of about 80 percent. A 60 to 65 pound straw bale will cover approximately 500 square feet.

Revegetation

Planting or transplanting appropriate vegetation is a primary means for long-term restoration of the health of a watershed. Most other treatments are temporary measures until vegetative cover can be restored. Accelerating revegetation consists of selecting appropriate species for the treatment area and introducing them to a new site in a manner allowing them to prosper and grow. Appropriate species are usually those found growing nearby. Methods include planting stem cuttings from plants such as willow, cottonwood, thimbleberry, coyote bush, or other species that are able to root from cuttings. Planting container grown or bare root stock, such as alder, tan oak, *Ceanothus*, Douglas fir, redwood, and grand fir also is a good technique. Planting is appropriate for treatment of areas that have stable footing, adequate temperatures, and enough water for plant survival. Correct choice of plant species and proper planting technique are critical.

Transplanting

Relocation of plants found growing near the treatment site is sometimes appropriate. Some species are best acquired by thinning surpluses in nearby thickets and stands.

Revegetation with Willow Sprigs

Willow (*Salix*) sprigging (Figure VII-57) can be an effective and inexpensive way to armor active headcuts and eroding gully banks, and to stabilize stream banks where water is flowing parallel with the bank. Willows must be planted in sunny areas where the soil stays moist throughout the dry season. Sprigs should be collected and planted when the willows are dormant. However, sandbar willows do not sprig well and should be avoided; cottonwood is a good alternative to willows. Sprigs should be at least 1/2-inch in diameter and 18 inches long. Sprigs, 2 to 3 inches in diameter and 3 to 4 feet long work best, and should be used in the most actively eroding places. Cuttings should be planted the same day they are cut. If it is not possible, then the entire cutting should be placed in water in a cold area.

Willows respond well to heavy pruning, so they can be collected heavily from a grove. Thin, however, instead of clear-cutting in order to leave cover for resident fauna.

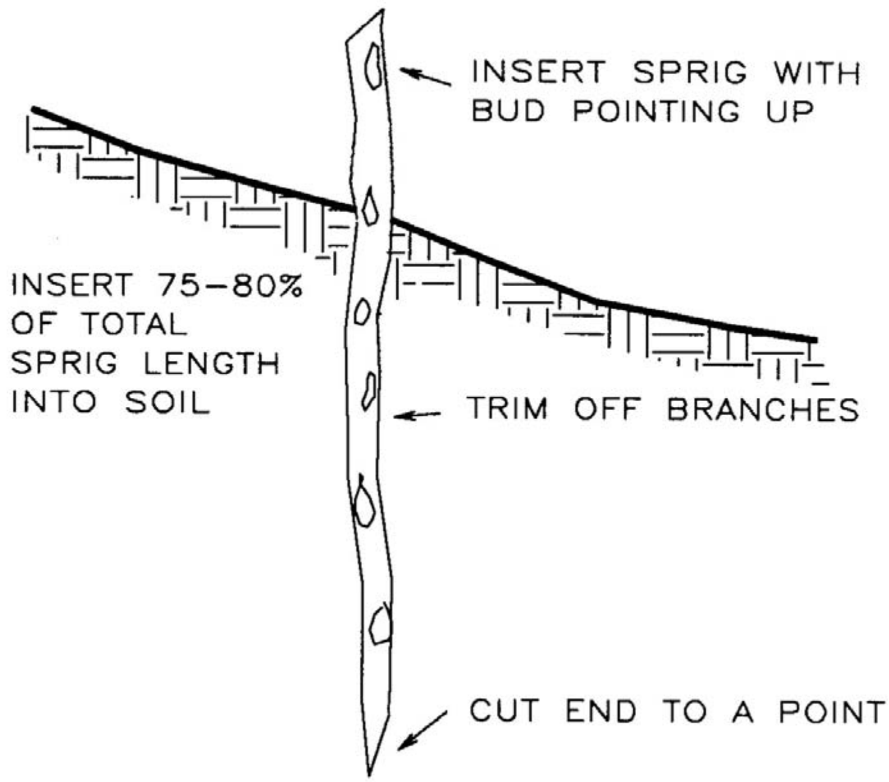


Figure VII-57. Willow sprigging. (Prunuske, 1987).

Plant the willows with the buds up, after sharpening the basal (bottom) end of the sprig with an axe or pruners right after it is cut from the tree. Sprigs should be driven into the soil 75 to 80 percent of their total length, at a slight angle downstream, to decrease their resistance to water flow. In hard soils an iron bar or a chain saw powered auger can be used to bore planting holes. After placing the cutting in the hole, tamp firmly around the cutting to remove air pockets in the soil. In soft soils, sprigs can be driven in with a wooden mallet or sledge hammer. Cut off the tops of the sprigs if they should split while hammering. Leave only one or two buds exposed.

In large rapidly eroding gullies, or along stream banks, appropriate spacing may be as close as one foot. In more stable gullies typical of relatively small watersheds, the sprigs can be placed 2 feet apart.

Cattle and deer tend to browse heavily on young willow. The revegetated areas may need protection by fencing, wire cones, or heavy netting.

Willow Wall Revetment

Willow wall revetments can be used for stream bank failures, eroding banks, and bank toe protection (Figure VII-58). Willow walls restrict sediment yield to a stream and also provide vegetation and canopy. The wall should be constructed along a stream bank at a height that will provide the willows with water during low flow months. If the wall is located upslope from the channel, irrigation may be required during summer months.

1) These walls are built at erosion sites along stream banks. If a rip-rap toe is desired, it should be placed below grade to prevent scouring. If more than one wall is to be constructed up a slope, there should be a three feet space between each successive wall.

2) Planting holes should be bored three feet apart from one end of the site to the other. Hole depth depends on the length of the willow poles being used. For example, an eight feet long willow pole requires a hole five feet deep. The poles should be two - three inches in diameter and as straight as possible. The poles should be set with the tops up and leaned slightly towards the bank at approximately a 15° degree angle to allow for the weight of the earth fill to be added later.

3) After the poles have been set and tamped, long, flexible willow branches from 3/4 to 2" in diameter are tightly woven through the standing poles. The woven branches should be packed down as tightly as possible. Both the woven material and the poles should be stripped of all small branches and tops less than two inches in diameter. These can be used later in the back fill brush material.

4) Once the wall is constructed, a backing of biodegradable erosion cloth or netting should be placed against the woven willow pole wall on the bank side. Using smaller tops and green willow branches, create a brush pack approximately one foot wide behind the netting. Backfill the wall with firmly packed down soil. All disturbed soil areas are mulched with litter and seeded. Each end of the wall can be anchored with 3/8" cable and attached to duck bill anchors to add stability.

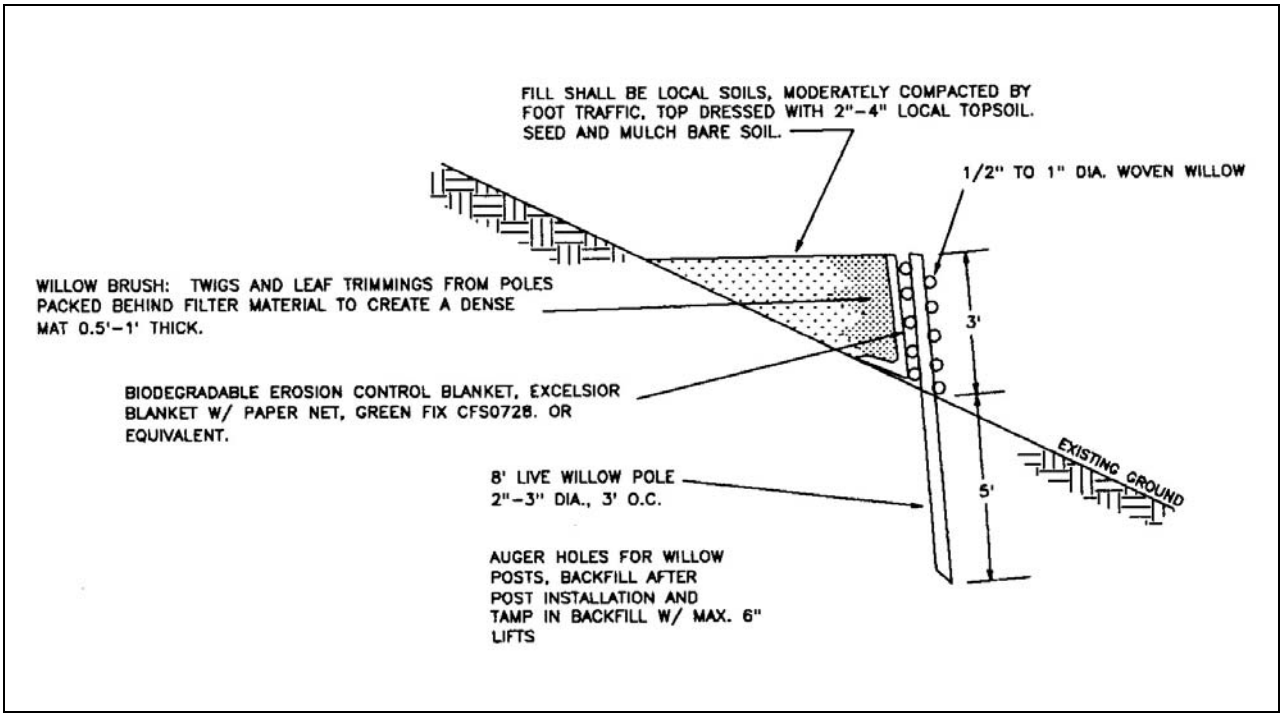


Figure VII-58. Willow Wall Revetment (L. Prunuske, 1997).

Brush mattress

Brush mattresses work well for bare eroding streambanks (Figure VII-59). These mattresses protect the stream banks from erosion caused by exposure and scour.

1) The disturbed bank should be sloped and smoothed to ensure that all willows are in contact with the soil. Excavate a toe trench two feet below streambed elevation at the base of the bank for the butt ends of the willow branches.

2) Partially drive wood, steel, or live willow stakes in rows on three foot centers along the area of the bank that will be covered by the mattress. After the stakes have been placed, lay live willow branches on the bank with their butt ends in the trench. It is best to use straight branches no shorter than four feet in length and approximately 2 to 1" in diameter. Place approximately twenty to fifty branches per linear yard, depending on their diameter. If the branches are not long enough to cover the upper bank area, several layers may be used, but it is necessary to lap, or "shingle," each added layer with the layer below it by at least eighteen inches (Figure VII-60).

3) Once the bank has been covered with a thick layer of willows, cross branches are placed horizontally over the bottom layer. These branches should be placed against the stakes and then tied to the stakes using wire or string.

4) The stakes are then driven into the bank a minimum of two feet. The deeper the stakes are driven in, the tighter the mattress will be held against the soil of the bank. After completion of the mattress, the trench should be filled with small boulders or rocks to anchor the butt ends of the branches. The entire mattress should be lightly covered with earth or fine streambed material.

Stream channel dimensions, hydraulic factors, available material and other factors may dictate variations to this general design.

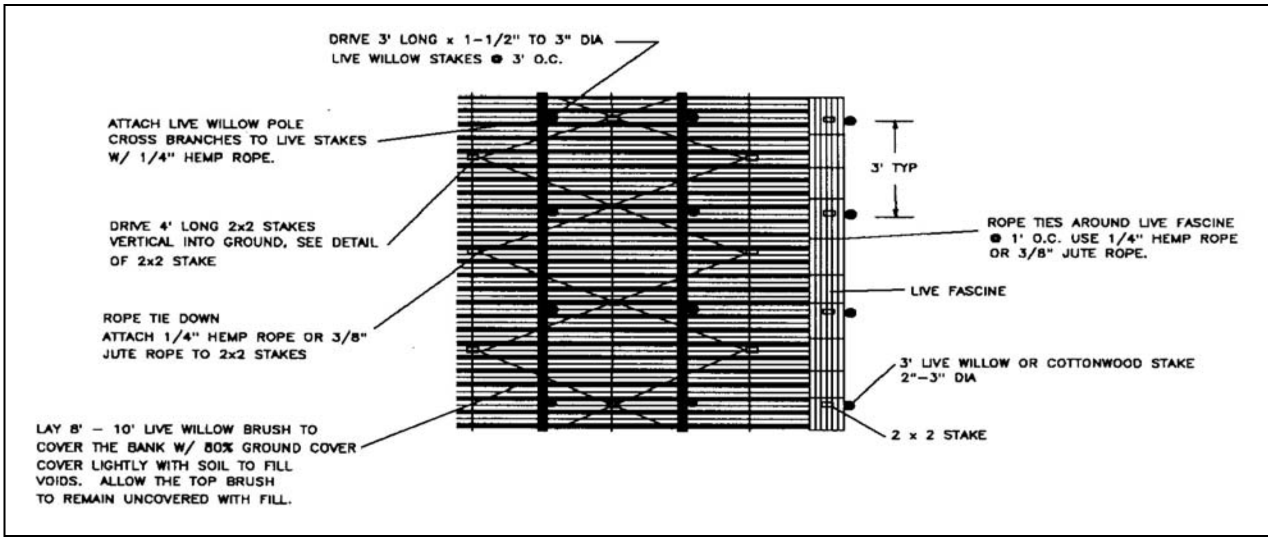


Figure VII-59. Brush Mattress Plan View (L. Prunuske, 1997).

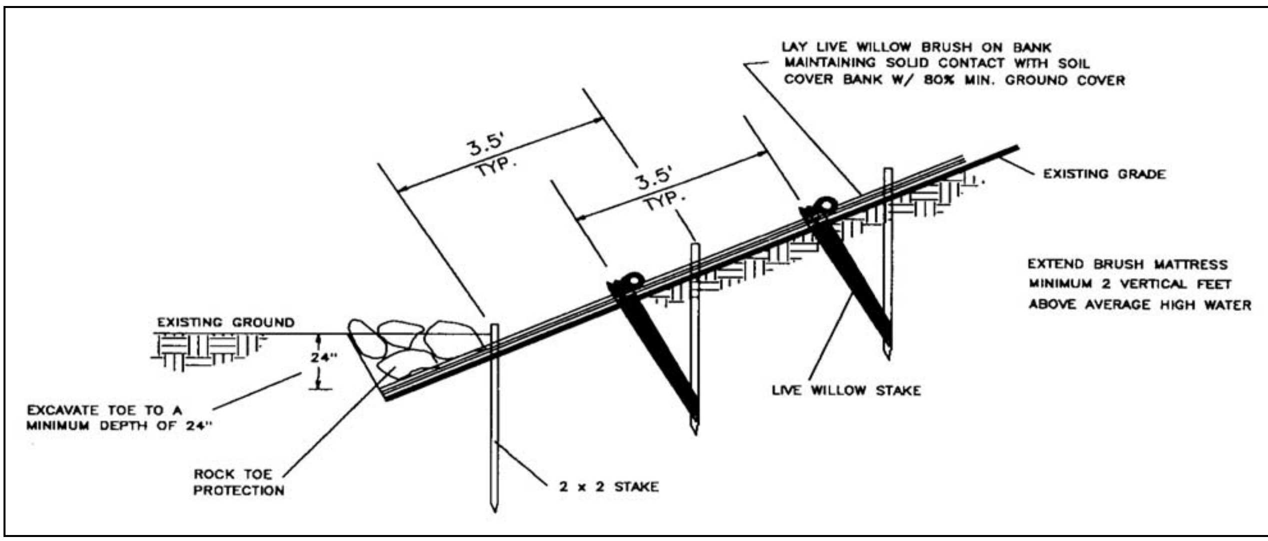


Figure VII-60. Brush Mattress Cross Section (L. Prunuske, 1997).

Willow Siltation Baffles

Willow siltation baffles are inexpensive structures that can achieve several objectives. Their function is similar to a wing deflector which can be used for bank protection and energy dissipation, as well as for channel constriction. Willow baffles are designed to work in series and pass flow through the structure, sort bedload, dissipate energy, and trap fines.

1) Dig toe trenches perpendicular to the bank approximately 1 2 - 3' deep. Extend the trenches into the stream channel a short distance. The baffles should be keyed into the bank at least three feet. The excavated material removed from the trench should be placed along the downstream side of the trench. Each successive baffle is installed at different angles. The most upstream baffle is placed at an acute angle with the bank, and the following baffles are placed at right-angles. The lower baffle is placed at an obtuse angle. The number and length of baffles is dependent on the dimensions of the stream channel and treatment area (Figure VII-61).

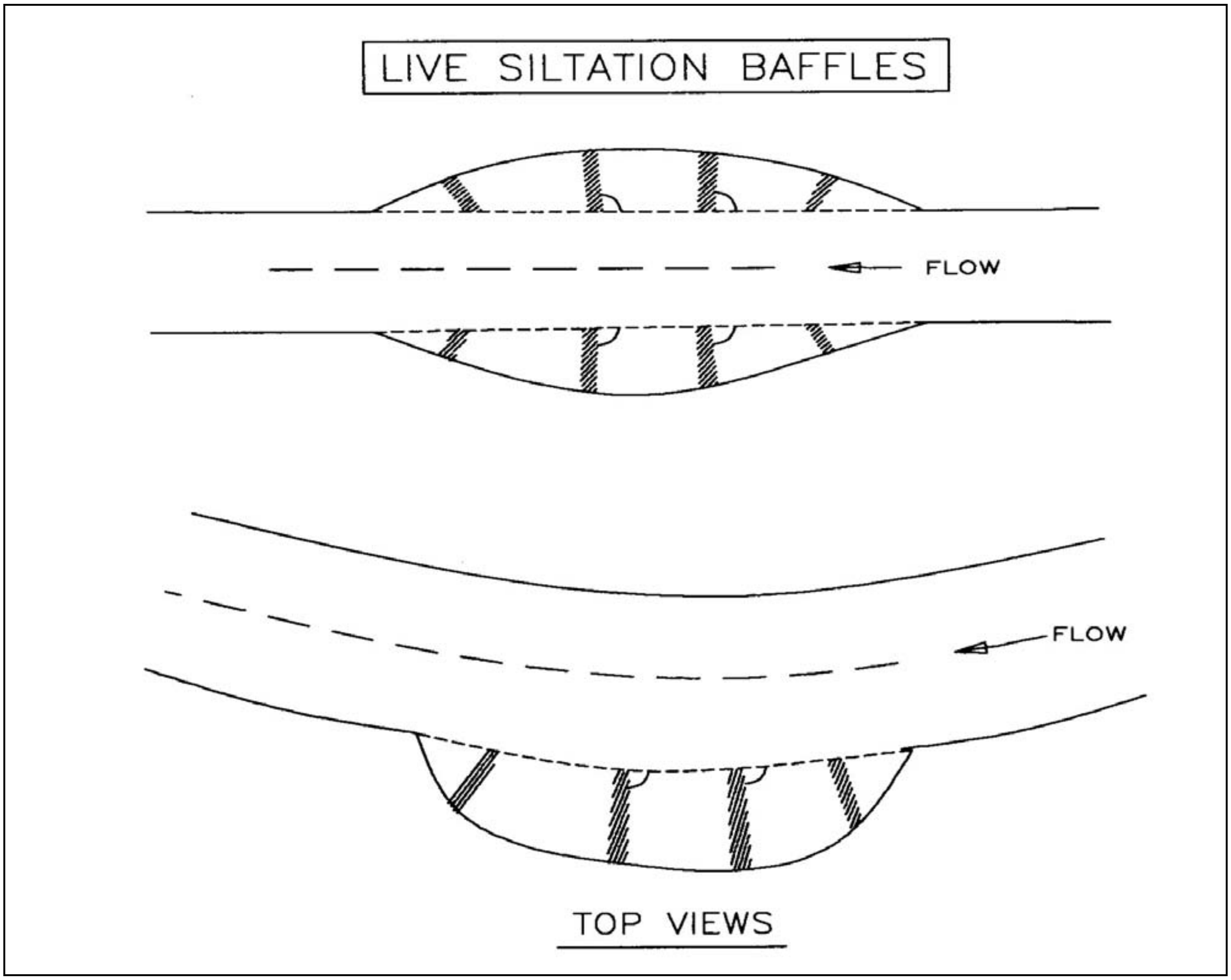


Figure VII-61. Arrangements of baffles (Schiechtl and Stern, 1996).

2) Willow branches approximately three to six feet long and 1/2" in diameter are placed in the trench pointing downstream . The ends of the baffles that extend into the channel have the willow branches wrapped around, forming an upstream facing "J." (Figure VII-62) The willows are densely packed with no gaps and form a standing mat. The trench is then back filled with streambed material and small cobble. Some topsoil may be placed at the bottom of the trench to help with root formation. Larger stone is placed on top of the backfill in order to secure the willow branches. The largest rocks available should be placed on the stream channel end of the baffle. Site specifications will be unique to stream channel dimensions, hydraulic factors, and available material and will dictate variations to this general design (Figure VII-63).

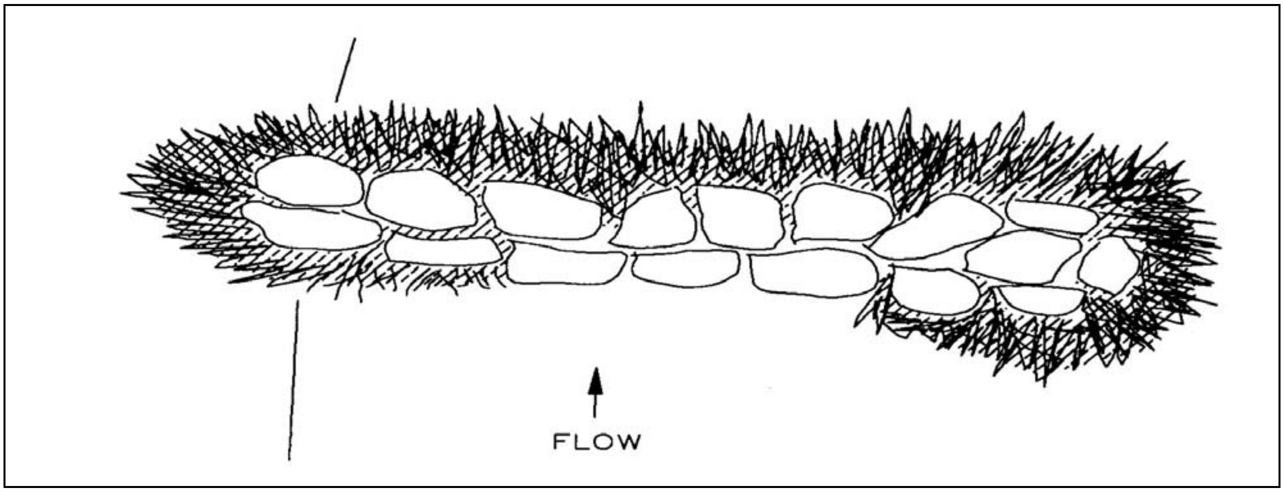


Figure VII-62. Top view of baffles (Schiechtl and Stern, 1996).

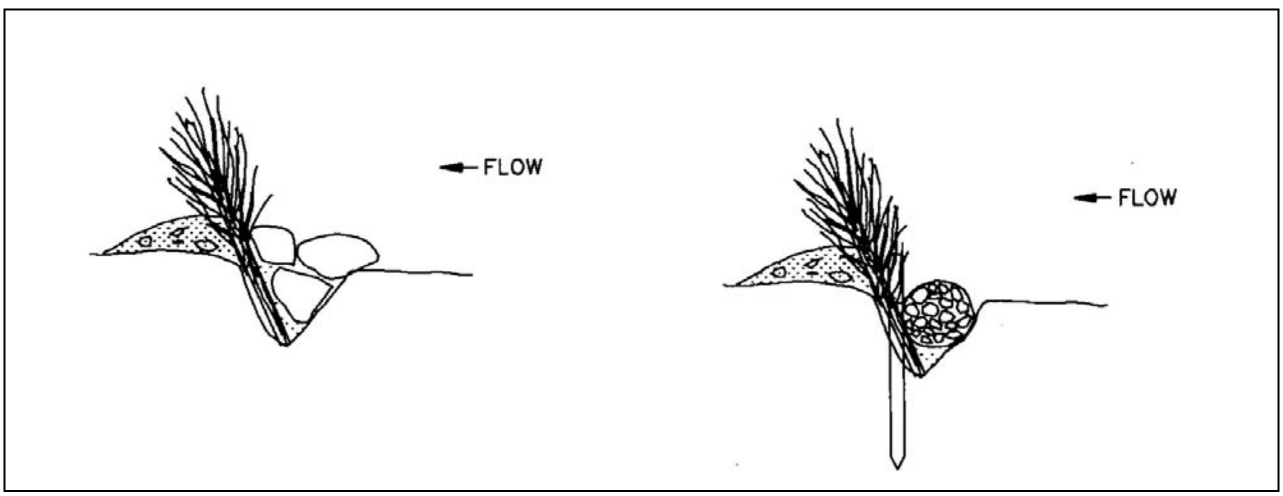


Figure VII-63. Side view of baffles (Schiechtl and Stern, 1996).

Planting Seedlings

Seedlings can be planted with shovels or western planting tools (also known as hoedads or planting hoes) in most situations. Planting bars may be used if the soil is not too rocky or compacted.

Power augers with carbide-tipped bits are also recommended for planting. Power augers come in two types: one with its own power head, and a second type that attaches to a chain saw power head.

A bucket, waterproof planting bag, or similar container is needed for carrying trees in the field. Use sawdust, peat moss, vermiculite or other moist material around the roots of bare root seedlings to keep them damp at all times. Do not keep seedlings immersed in water since it reduces oxygen and plants may suffocate. In some areas it is necessary to use shade cards or shingles to shelter seedlings. Plastic netting or tubes, spray repellents, or bud caps can be used to protect plants from animal damage.

Seedlings are delicate and must be handled carefully (Figure VII-64). For highest survival, treat trees carefully, and plant them immediately. If planting must be delayed a few days, keep the boxes in a cold, protected place. For containerized seedlings, cut the box down level with the container so that air can circulate between the trees. Keep trees out of rain and wind. To check if trees need water, feel the media at the bottom of the tube. If it is not damp, water the trees, and allow excess water to drain. In cool, damp weather, the biggest threat to seedlings is from mold.

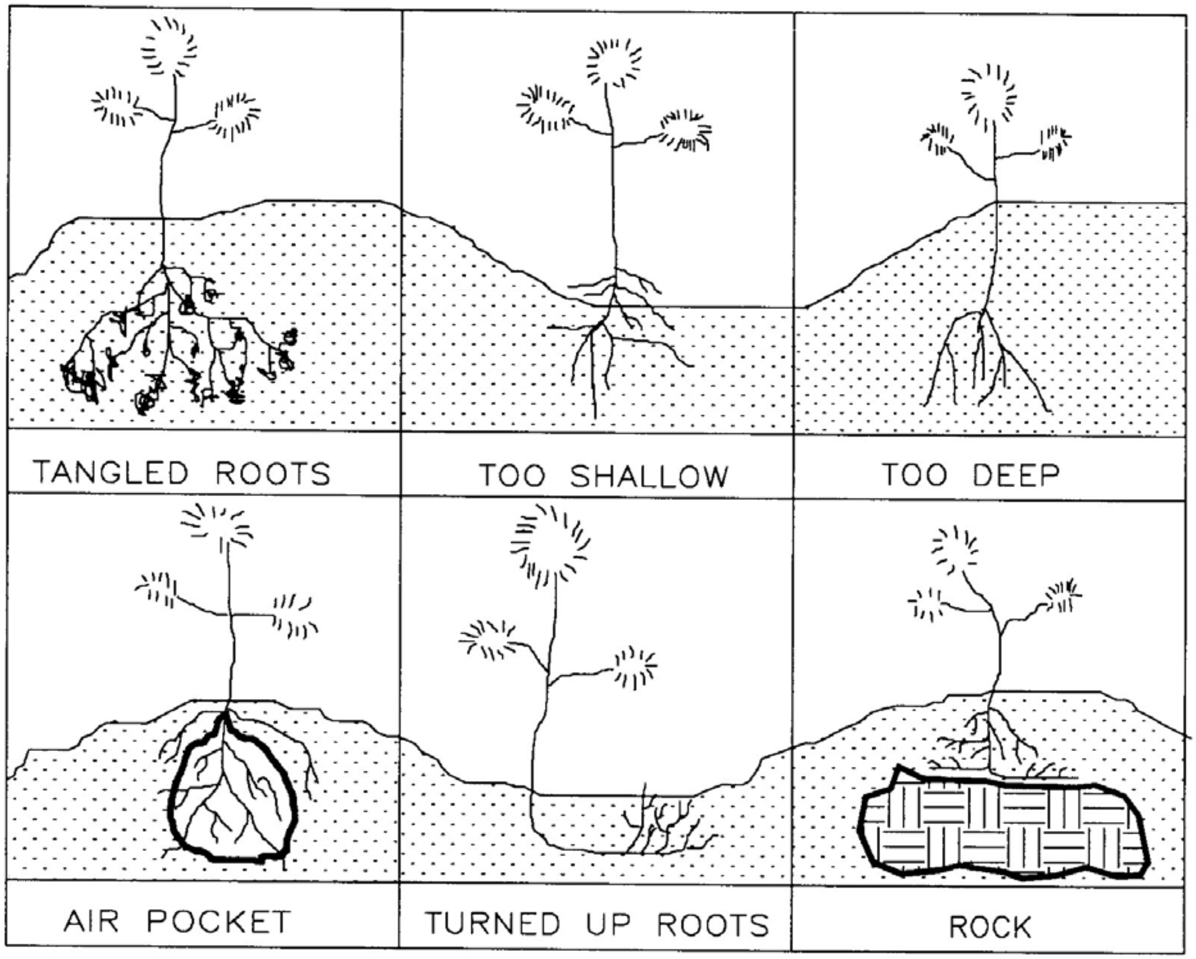


Figure VII-64. Problems to avoid during tree planting.

Ideal storage conditions for bare root seedlings are a temperature of 33E Fahrenheit and high humidity. If available, refrigerated storage is best. Check packing material around roots to make sure it is moist. If it is drying out, wet thoroughly and allow excess water to drain off. Keep roots moist, but not the tops. Wet tops can easily become moldy. The biggest threats to bare-root seedlings are dried roots and mold formation; which occurs if the trees become too warm.

Ideal planting days are cool and cloudy, with little or no wind. If possible, avoid planting on warm, windy days. The soil should be moist. Care in planting is more important than speed. Make sure roots never become dry. Planters should only carry about 50 trees at a time. Trees should be carried in a waterproof bag or bucket with plenty of moist material packed around the bare roots to keep them damp. Trees remaining in boxes should be left in boxes and kept in a cool, shady place. Ideally, bare root boxes should be kept refrigerated or packed on ice or snow.

Competition from weeds, grass, brush or other trees can kill or retard growth of seedlings. Choose areas free from this competition, or clear at least a three-square-foot area before planting. Seedlings should not be planted under direct shade of trees, or closer than 6 feet to existing brush, unless lethal temperatures are anticipated.

Clear away loose organic material such as leaves, grasses, etc. from the planting spot to expose mineral soil. If organic matter gets into the planting hole, it can decompose and leave air space. Roots will dry out when they grow into these spaces.

Open up the hole, making sure it is deep enough for the roots to be fully extended (Figure VII-65 and Figure VII-66). Take a tree out of the planting bag or bucket only after the hole is ready. When exposed, fine roots can dry out in as little as 30 seconds. Remember to remove the container before planting a containerized tree. This can be done by cutting container or by pushing up gently on the roots with a stick or broom handle. If roots are curled or bunched up, the tree will not be able to absorb water correctly, will often weaken and die, or may blow down in later life due to poor root structure.

After removing a seedling from the container, hold it in place in the hole, making sure roots are straight, fully extended, and that the seedling is neither too shallow nor too deep. Fill the hole, allowing soil to fall in around the roots. Tamp with hands or with your heel. Fill with more soil, if necessary, and tamp. Tamping is important. If soil is not firmly packed around the roots, air pockets will remain that can dry the roots, and the seedling may be weakly anchored. Addition of fertilizer and plant vitamins at the time of planting is not generally necessary.

Again, care is more important than speed. In regard to spacing, it is better to pick a planting spot shaded by a stump, log or rock, than to strictly follow recommended spacings. During planting of riparian species, care should be taken to ensure that roots have ready access to moist soil.

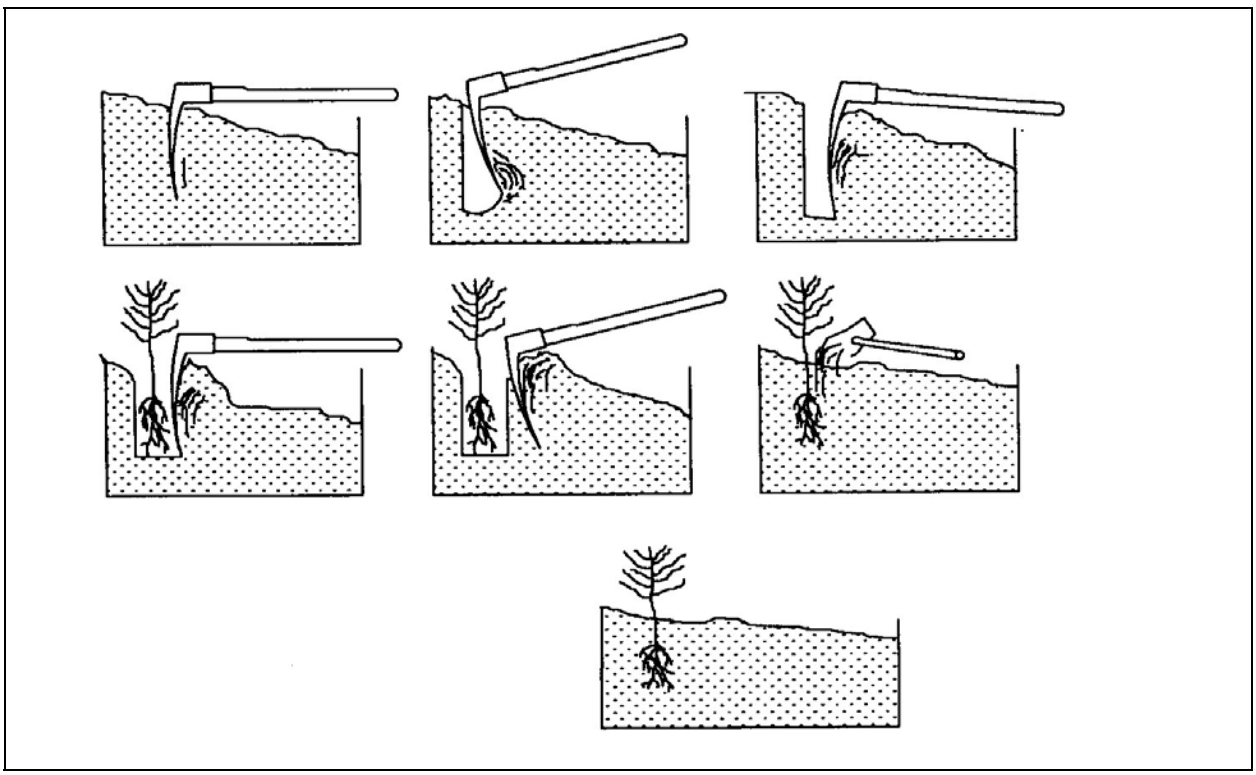


Figure VII-65. Steps in tree planting with hoedads. (California Department of Forestry, 1978).

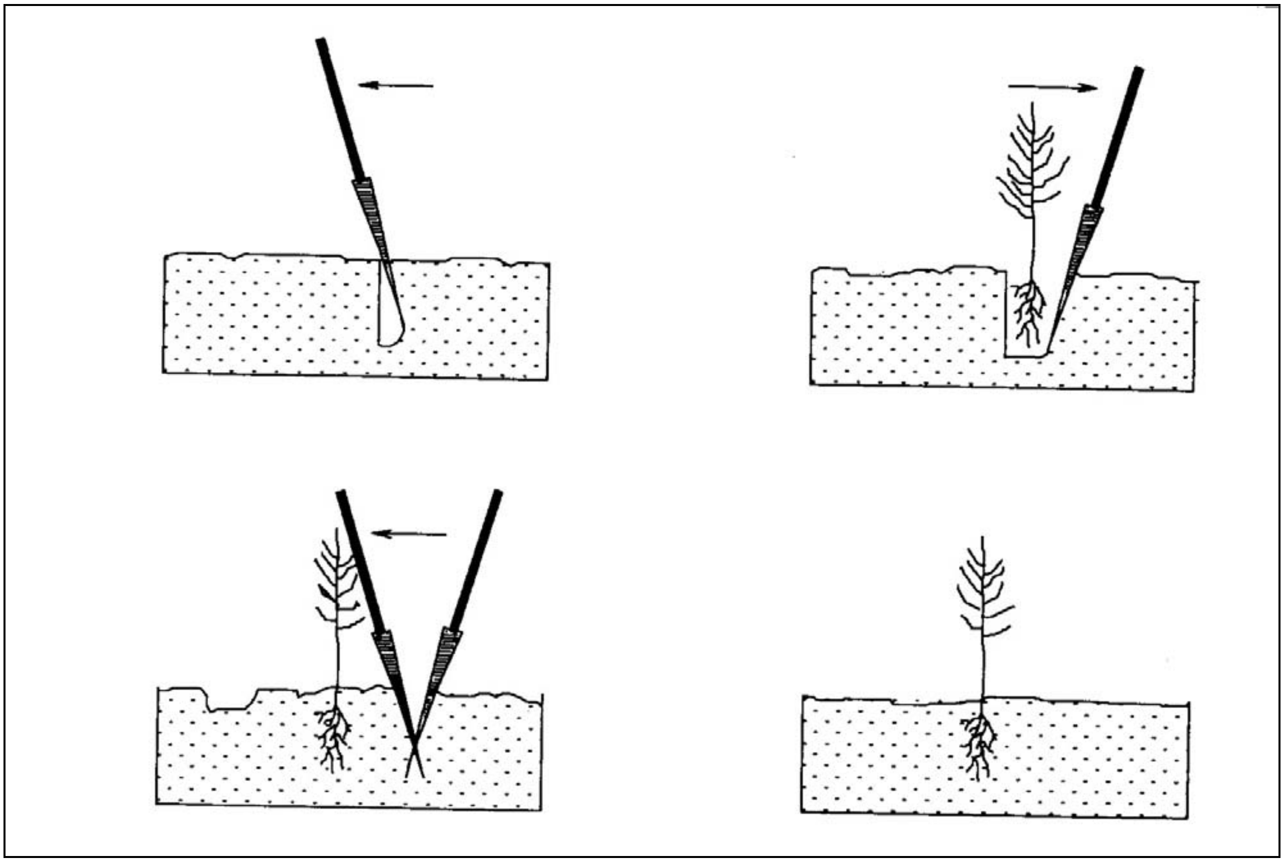


Figure VII-66. Tree planting. Planting bar method. (California Department of Forestry, 1978).

Checkdams

Checkdams are small dams constructed across a gully, ditch, or stream to reduce water velocity and trap sediment. All checkdams fall into two broad categories: permeable and impermeable. Permeable check dams allow water to pass through the dam face. Sediment is deposited more slowly above them than if water flow is stopped completely, but such dams are more resistant to blowouts than impermeable dams. Checkdams can be constructed from a variety of materials. Materials used to construct permeable checkdams include strawbales, woven willow branches, brush, loose rock, gabions, and logs. Impermeable checkdams include redwood board, compacted earth, mortared rock and concrete structures. Table VII-1, Selecting a checkdam type, summarizes various checkdams and their uses.

Guidelines for checkdam construction:

- A series of low dams is usually more effective than fewer high dams.
- Use a hand level to space checkdams so that the toe of one is level with, or slightly below, the spillway of the next downstream dam (Figure VII-67).

- All impermeable dams and most permeable dams require a spillway to reduce bank erosion and lessen the possibility of the stream eroding a new channel around the structure. The spillway should be large enough to accommodate normal storm flows. Be careful to aim spillway discharge toward the bottom of the gully, not the sides, even if this requires that the spillway be off-center.

- Always provide a non-erodible energy dissipator (or apron) for the checkdam discharge.

- The top of the checkdam must be level.

- Key all checkdams securely into gully banks and bottom.

- Construct checkdams perpendicular to flow.

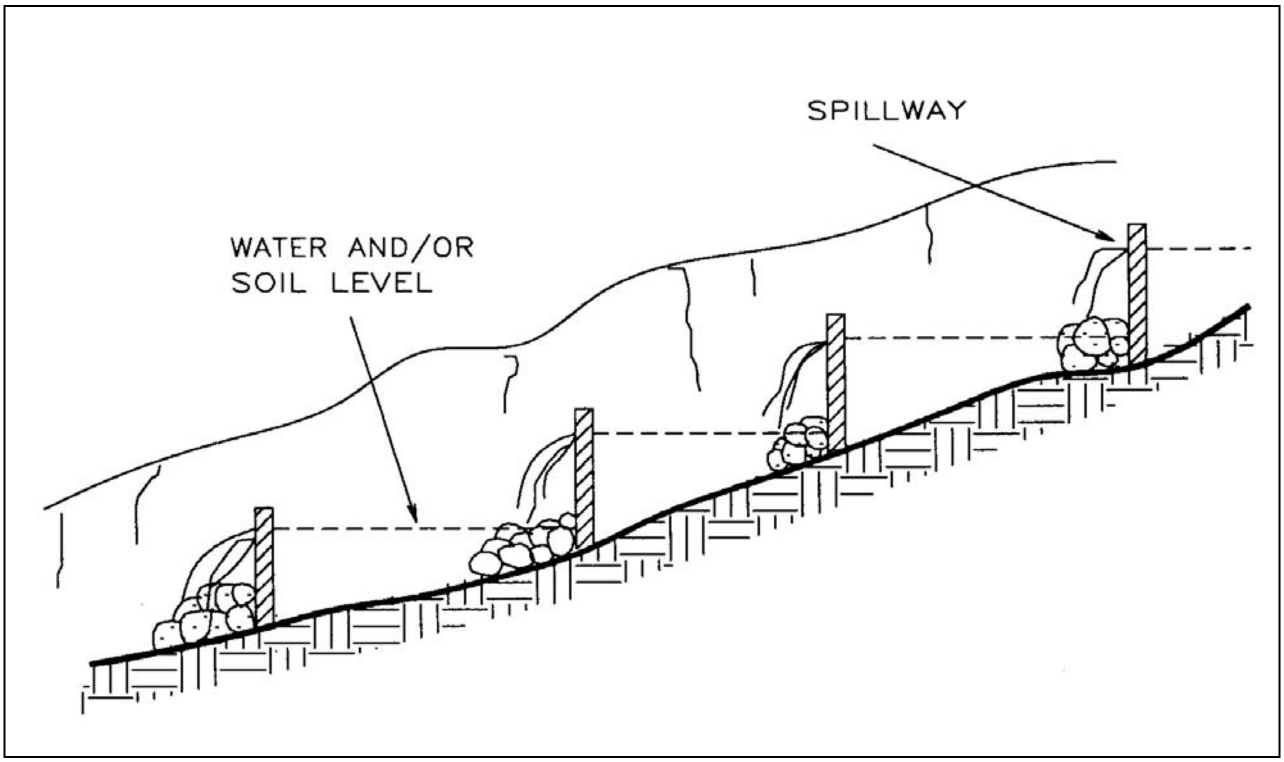


Figure VII-67. Checkdam placement. (Prunuske, 1987).

Table VII-1. Selecting a checkdam type (Prunuske, 1987).

Type of Checkdam	Gully Activity*	Optimum Gully Size	Soil Particle Size	Durability	Special Site Conditions	Common Reasons for Failure
Strawbale	low	3-6 ft. wide, up to 3 ft. deep	fine to coarse	2-3 years	Use only in areas that can be seeded or where natural vegetation will occur quickly.	Bales not keyed into banks and bottom securely; animal damage; gully too active; no follow-up revegetation.
Woven Willow	low	up to 4 ft. wide, up to 3 ft. deep	coarse	indefinite	Use only in winter swales and where minor flooding is acceptable. Best in gravelly soils with high organic content.	Sprigs planted upside down, too sparsely, not deep enough or too late; insufficient water in dry season; animal damage.
Brush	low to moderate	up to 4 ft. wide, up to 3 ft. deep	coarse	2-3 years indefinite if live willow stakes used		Brush not anchored securely; insufficient amount of brush; large poles used instead of smaller, leafy branches.
Loose Rock	low to high	up to 10 ft. wide, up to 10 ft. deep	fine to coarse if filter fabric used	indefinite	Rock on-site, or site accessible to dumptruck or loader.	Rock too small; not securely keyed into banks and bottom; spillway too small.
Gabion	low to high	One gabion width less 2 ft. key width, 3-10 ft. deep	fine to coarse if filter fabric used	20+ years	Rock on-site, or site accessible to dumptruck or loader.	Not securely keyed to banks and bottom; energy dissipator does not extend far enough downstream; spillway too small.
Log	low to moderate	up to 4 ft. wide, up to 3 ft. deep	coarse	5-20 years depending on type of wood	Works best in gravelly soils with much organic matter such as leaves and twigs.	Not securely keyed to banks and bottom; energy dissipator does not extend far enough downstream; gaps between logs too large; spillway too small.
Redwood Board	low to high	2-10 ft. wide, 2-5 ft. deep	fine to coarse if filter fabric used	20+ years depending on quality of redwood		Not securely keyed to banks and bottom; poor quality wood used; energy dissipator inadequate; active gully bank erosion; spillway too small.
Grouted Rock	moderate to high	3-10 ft. wide, 3-10 ft. deep	fine to coarse	50+ years		Not securely keyed to banks and bottom; air spaces left between rocks; energy dissipator inadequate; spillway too small.
Concrete	moderate to high	3-10 ft. wide, 3-10 ft. deep	fine to coarse	50+ years		Not securely keyed to banks and bottom; energy dissipator inadequate; spillway too small.
Compacted Earth	high	10-40 ft wide, 10-30 ft deep	fine to coarse	indefinite	Check with design engineer	Insufficient soil compaction; spillway not protected with non-erodible armor; energy dissipator too light and/or does not extend far enough downstream.

* **Low** - Headcut is shallow (less than 3 feet deep) and does not grow noticeably during heavy rainfall. Banks are gently sloped and mostly covered with grass, tree roots or other vegetation.

Moderate - Headcut is shallow, but expands noticeably during winter storms. Banks are gently sloped and mostly covered with vegetation with occasional steep areas of raw, exposed soil.

High - Headcut is more than 3 feet deep and moves rapidly uphill during heavy rainfall. Banks are steep with little vegetation.

Redwood Board Checkdams

Redwood board checkdams are suitable for spans up to 10 feet wide and up to 3 feet high. The redwood should be heartwood and free of large knots (Figure VII-68).

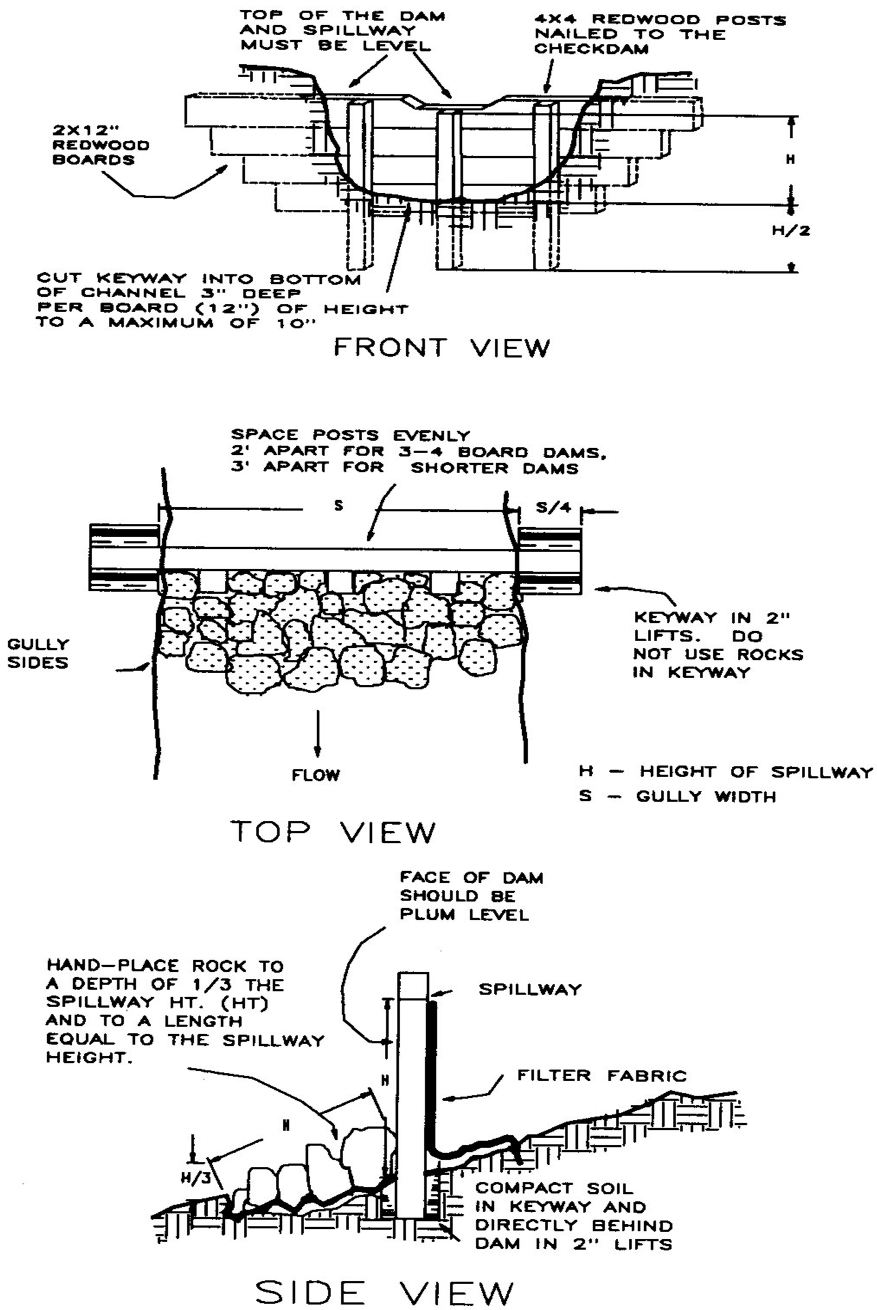


Figure VII-68. Redwood board checkdam. (Prunuske, 1987).

Brush Checkdams

Brush checkdams are very suitable to treat erosion sites in ephemeral gullies and headcuts. Their porous design allows water to pass through the structure and retain sediment. Since they are not hard obstructions, they do not divert water and cause bank scour. Live willow, cottonwood, fir and other types of branches which are usually pruned from the lower eight feet of a tree trunk can be used as “brush” in the construction of these dams. Any fine textured vegetative material raked up from under trees such as forest duff, pine needles, leaf mulch, straw, and rotted log pieces broken down with a hoe or mattock can be used as “litter” for mulch in each project type. These vegetated check dams can be constructed in a series or singularly in the same manner as the other check dams discussed.

Brush and Rock Checkdam

These are suitable for use within small, low activity ephemeral gullies (Figure VII-69).

1) Grade the gully banks to the slope angle of existing undisturbed banks. Retain the excavated soil for later use at completion of the project.

2) Place a six inch layer of litter along the gully=s bottom and along the sides to be treated.

3) Beginning at the downstream end of the gully, place an eight inch thick apron layer of brush on top of the litter. Butt ends must point downstream.

4) Near the upstream end of the brush apron layer, stack a row of rocks on top of the brush layer about one foot high perpendicular to the gully. When available, flat rocks are the most stable and preferable.

5) Place about a four foot layer of brush parallel to the gully, butt ends downstream, and extending just downstream over the rock dam.

6) Place another row of rocks at least one foot high across the middle of the brush layer. While adding rocks, walk on the brush to compact it as much as possible.

7) Repeat steps 4 - 6 to raise the dam to the desired height.

8) Weigh the last layer of brush with a row of rocks to hold it in place.

9) Cover the upstream face of the dam with the soil excavated during the initial site grading process. Mulch the soil layer with a four inch layer of litter. Disturbed areas not treated by the brush should be seeded and mulched.

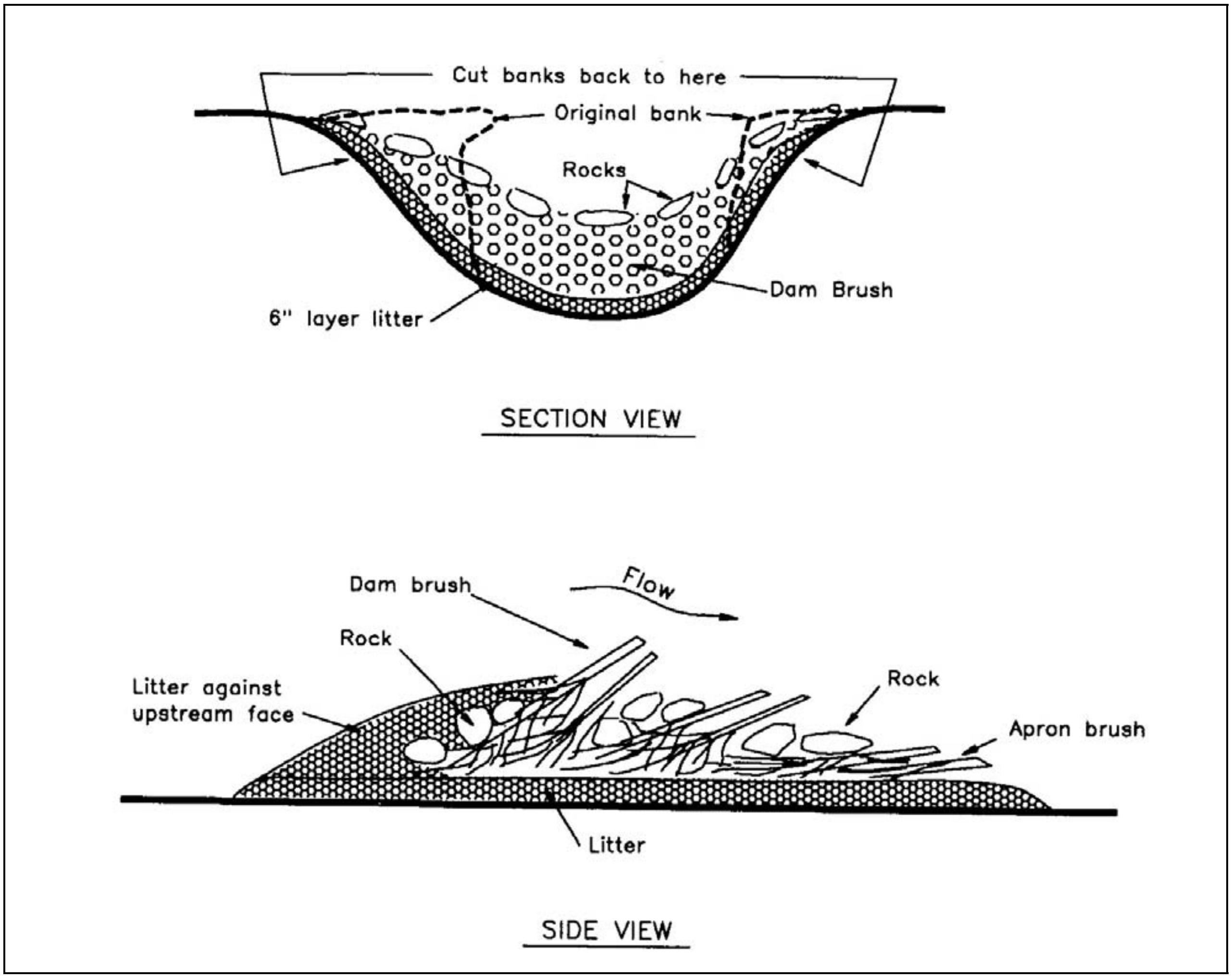


Figure VII-69. Brush and Rock Checkdam (Kraebel and Pillsbury, 1934).

Post Brush Checkdam

These are suitable for use within large, moderate to high activity ephemeral gullies (Figure VII-70).

1) Grade the gully banks to the slope angle of existing undisturbed bank. Retain the excavated soil for later use at completion of the project.

2) 2) Metal “T” posts, or wooden posts two to four inches in diameter, should be set on two foot centers across the watercourse and be driven a minimum of eighteen inches into the ground. Live willow poles can be used if high ground water is present year round.

3) 3) Layer small diameter brush parallel to the gully to act as a filter and soil erosion blanket. Each layer should be approximately six inches thick. The butt ends should extend beyond the posts at least six inches in an upstream direction.

4) Weave brush material through the posts at least one foot thick and continue adding material to the top of the posts. Attach branches or boards across the posts using rope or string to

hold the brush down firmly. Compact each layer of branches to ensure that no large gaps are present in the checkdam. At completion, the brush should be layered to the tops of the banks while leaving the middle section slightly lower to form a channel for flow.

5) Seed and mulch any disturbed areas after completion. Erosion cloth may be applied, if desired, behind each checkdam.

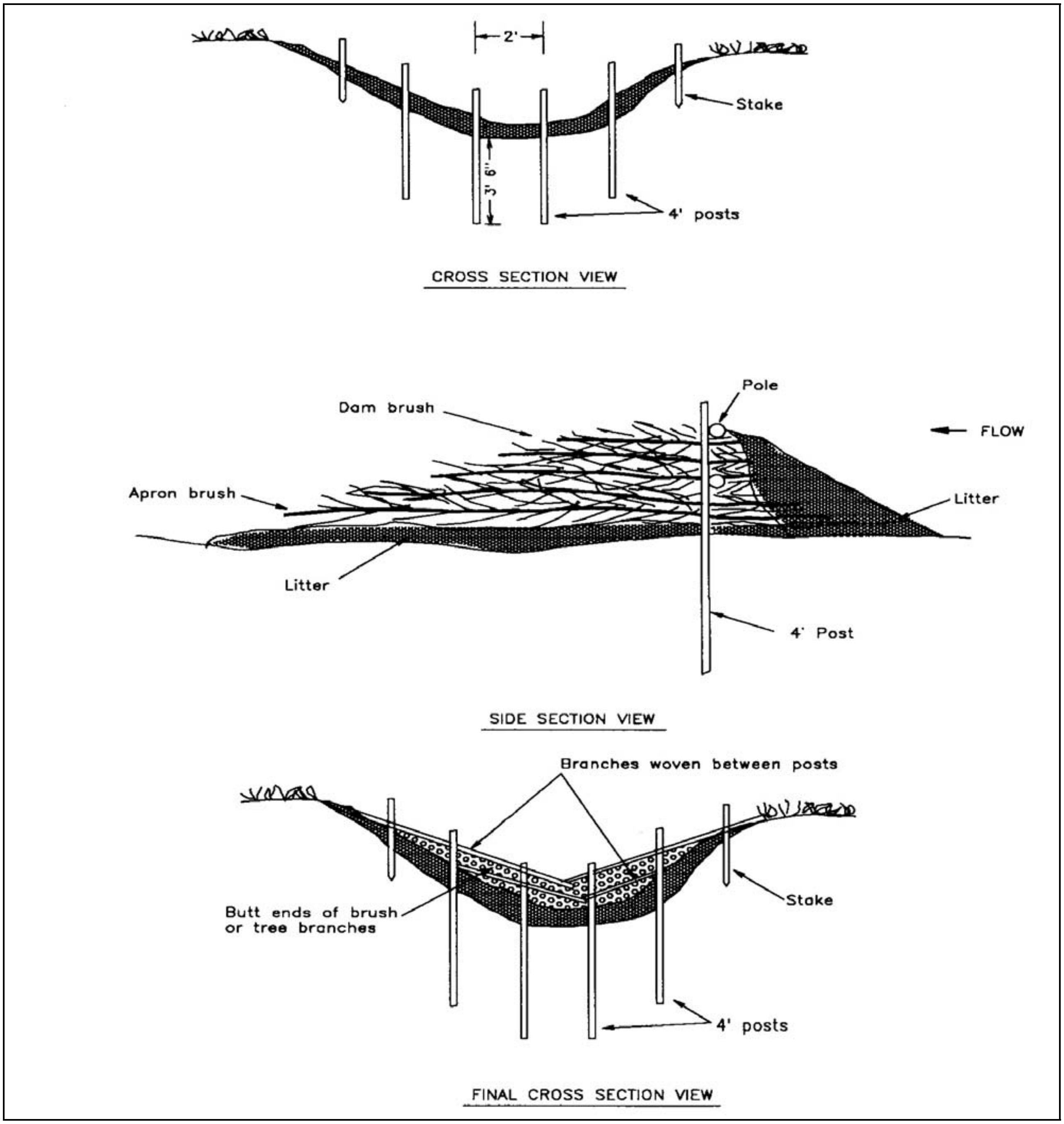


Figure VII-70. Post Checkdam (Kraebel and Pillsbury, 1934)

Tree Checkdam

This technique can be used where small trees are plentiful and need thinning (Figure VII-71).

1) Grade the gully banks to the slope of its undisturbed bank slopes. Retain the excavated soil for later use at the completion of the project.

2) Place a six inch layer of litter along the gully=s bottom and its sides where the first row of trees will be placed to form an apron.

3) Lay the first row of small trees (< 8' tall), butts downstream, across the gully and up the sides to form the apron.

4) Continue stacking several layers of trees, butts downstream, across the gully bottom and up the sides, staggered in an upstream direction. They should be piled to the desired height in the center of the gully, and several feet higher on the banks depending upon the depth of the gully.

5) If available, large rocks placed on the upstream end of the apron will increase the stability of the dam, especially in a gully subject to high flows.

6) Finally, place the soil excavated during the earlier grading process against the upstream face of the dam, and cover it with a two to three foot layer of litter. Seed and mulch disturbed areas.

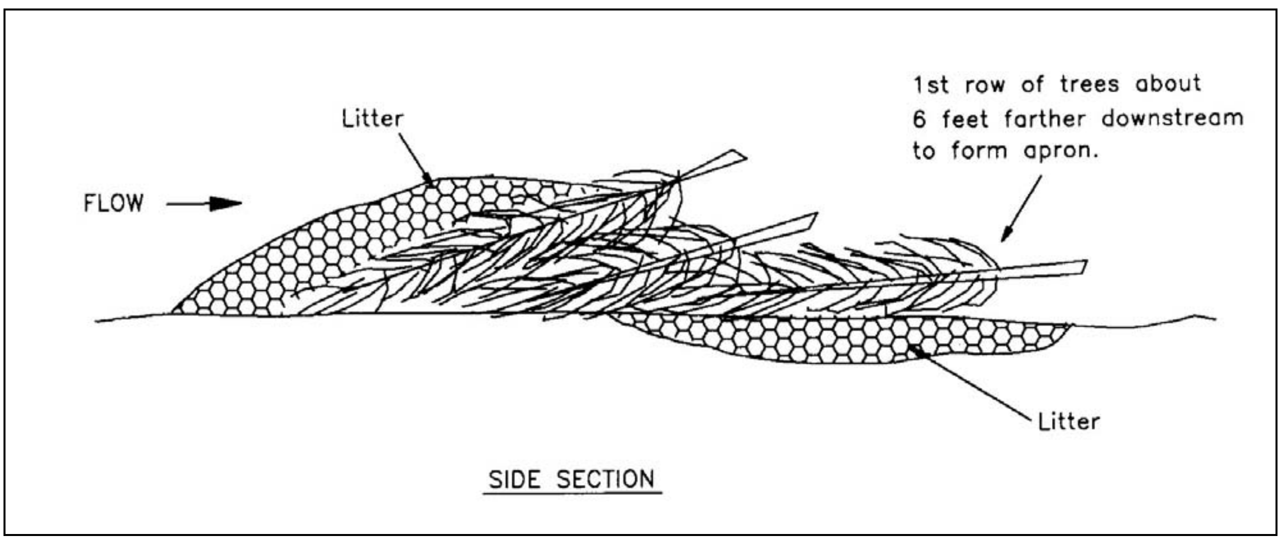


Figure VII-71. Tree Checkdam (Kraebel and Pillsbury, 1934)

Brush and Rock Mattress Headcut Repair

A headcut is a vertical break in slope at the uphill end of a gully or section of gully. Some gullies have multiple headcuts. Headcuts form a waterfall plunge which causes soil to erode from the scour of the cascade. This loss of soil causes the gully to migrate uphill. Headcuts often occur when water is concentrated by road drainage systems below stream crossings. Headcuts are also often associated with slope slumping along stream banks or in upslope areas.

1) Grade the banks near the upper end of the headcut to the slope of existing undisturbed bank slopes.

2) Place a six inch layer of litter in the gully and its side slopes along the area to be treated.

3) Cover the litter with a apron layer of brush. Start at the downstream end of the headcut and work upstream to the top. The butt ends of branches should be pointed downhill.

4) Cover the brush with a layer of large rocks, which will stabilize the mattress against the force of runoff. Use flat rocks where possible. Disturbed areas should be seeded and mulched (Figure VII-72).

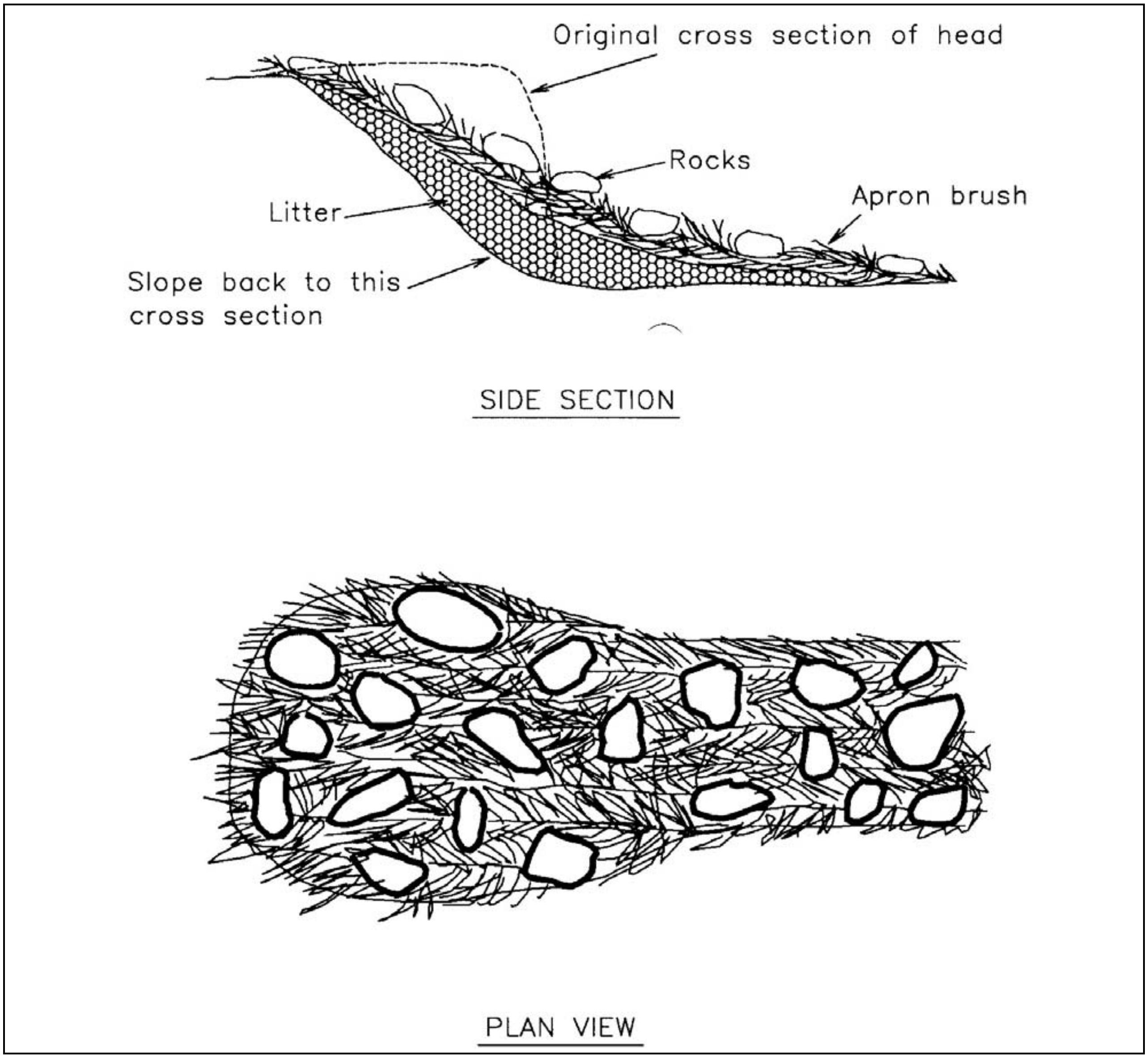


Figure VII-72. Brush and Rock Mattress (Kraebel and Pillsbury, 1934)

Waterbars

Waterbars (Figure VII-73) are a temporary means of breaking surface flow over sloped sections of road. They can be constructed with hand tools or heavy equipment. Waterbars are extremely effective at preventing rilling. They consist of a shallow ditch and rounded berm placed diagonally across the road surface. Often, they must be reconstructed every year because they either wear down during summer or are so annoying to those who regularly use the road that they are graded out in spring.

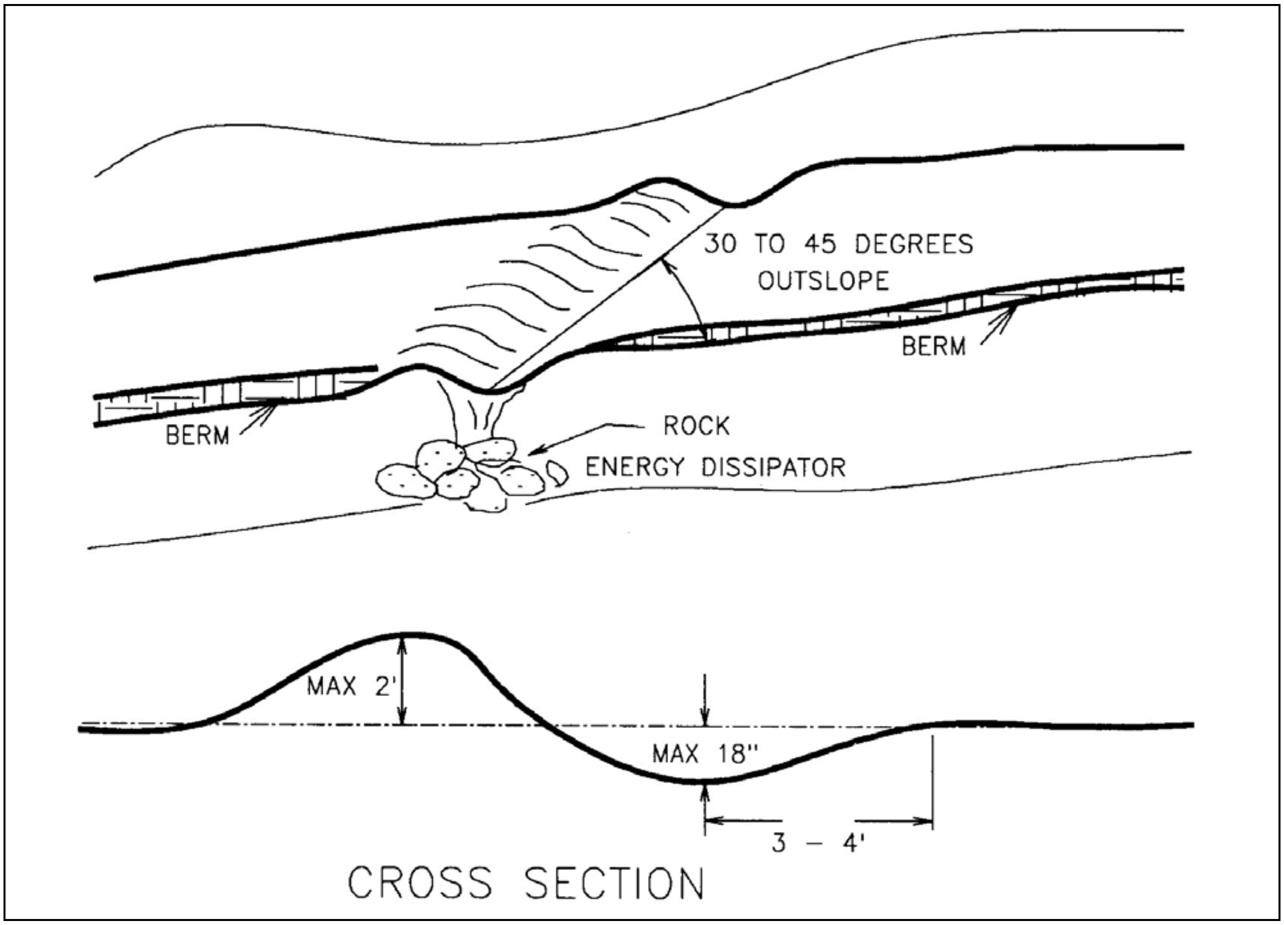


Figure VII-73. Waterbar.

Waterbars can be made easier to drive over by increasing the width and thereby reducing the slope of both the ditch and the berm. Installing waterbars in series will reduce the flow volume and hence the cutting action at each individual waterbar. Generally waterbars are spaced by dividing the road grade into 1000 feet. For example, if road grade is five percent, waterbars should be spaced approximately every 200 feet.

Waterbars can be reinforced with logs, gravel, or concrete. The outlet of the waterbar should open onto a wooded slope, existing stable channel, or onto a resistant slope that will not be adversely impacted by additional water. It may be necessary to create an energy dissipation mat by placing rocks or logs on the slope where water spills off the road.

Rolling dips function like waterbars when used as road cross drains. However, they do not require as much maintenance when properly installed, nor do they irritate motorists as much as waterbars. Rolling dips are installed by gradually ramping the road running surface down to a slightly outsloped low spot that is built across the roadbed, and then gradually ramping back up to the road grade. These installations often extend for a hundred feet or more. The low spot need only be about 12 inches below road grade in most installations. Site selection for rolling dips is similar to that used with waterbars.

Exclusionary Fencing

Streams passing through agricultural land are often adversely affected by livestock. Livestock can break down stream banks, destroy riparian vegetation, and by constant browsing, prevent new vegetation from becoming established. Overgrazed stream banks are highly susceptible to erosion and can add a significant amount of fine sediment to a stream. The best way to protect the riparian corridor and water quality of the stream is to exclude livestock access to the stream. This can be achieved by fencing the stream and riparian zone.

Generally, cattle require access to water every 1/4 mile. If livestock access to the stream for water is the only alternative, access points can be provided in areas with hard substrate where the stock will have the least effect on stream habitat. In most cases this will require fencing to cross the creek. In some instances, it may be more useful to develop an off stream water supply for livestock. There are also grazing rotation schemes that can alleviate effects to streams and riparian zones. The NRCS is a good source for further information on rotational grazing plans.

If exclusionary fencing is selected as a project, the DFG District Wildlife Biologist should be consulted prior to construction to make certain the location and type of fence will not be detrimental to wildlife in the area. Exclusionary fencing is constructed approximately parallel to the stream channel to keep livestock out of the stream and riparian zone. A setback of at least 25 feet from the stream bank should be used to establish an effective riparian zone.

Many types of fencing can be used. High-tensile wire fencing is probably the quickest and most economical to install. Electrical fencing can be economical to install but may require frequent maintenance. Barbed-wire, woven wire, wooden fence, or solid walls are more expensive to install. Regardless of the type of fence constructed, there will be an ongoing need for periodic maintenance.

Four or five strands of wire are usually necessary for permanent installations. To allow for wildlife passage the bottom wire is placed 18 inches from the ground. Redwood, cedar, yew, black locust, or pressure-treated posts are recommended for the wooden brace posts and corners.

A description of the construction of the many different types of fencing is beyond the scope of this manual. DFG's A *Gardener's Guide to Preventing Deer Damage* is a good reference on costs and designs used (Coey, 1994). NRCS is also a good source of information on fencing and improving grazing practices in watercourse areas. Many alternatives exist which have benefits to both stream channels and livestock production.

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