

SECTION 5 - DETAILED DESCRIPTIONS OF EROSION REPAIR TECHNIQUES

Described in this section are 16 different types of erosion repair methods. Each description contains a brief overview of the repair method, the circumstances in which it is most appropriate, its anticipated environmental value, its relative costs, and its potential impacts. Descriptions are not exhaustive, and should only be used in conjunction with consultation from a qualified erosion repair professional, the Santa Clara Valley Water District, and relevant regulatory agencies.

Even the most well-meaning erosion repair designs can have negative impacts on a stream if they are not planned, designed, and constructed properly. Poorly placed rocks or woody material can cause bed and bank scour/erosion, excessive sediment deposition, and/or decreased channel capacity. For this reason, it is essential that the project is designed to accommodate the site's particular geomorphic location, channel form and depth, flow velocity, and site constraints. This typically requires a physical, or "geomorphic" assessment by a trained professional.

To protect both your property and its value, the goals of any streamside bank protection or erosion repair project should be to restore stability and leave the site in a better ecological condition than it was before. The first erosion repair method, the modified flood plain, will provide the best long term, ecologically friendly and most stable results. Methods 2 through 8 use bioengineering methods. Bioengineered bank stabilization methods typically involve two components:

- Regrading the upper streambank to establish or re-establish a floodplain, with terraces where possible.
- Planting native riparian vegetation on the streambank and terraces in order to restore and provide long-term stability.

If soft methods of protection are not feasible due to highly erosive forces, then there is probably a channel dimension, hydrology and/or morphology problem. Hard bank protection can cause more erosion and damage in the channel, along the downstream and/or upstream banks, as well as on the opposite bank of the repair site. Any consideration of the use of hardened materials should be with caution and with an assessment of the impacts that may occur.

Erosion repair methods 9 through 11, incorporate bank armoring which should be avoided. The use of log and rock flow deflecting structures as described in method 1 is less expensive and a more environmentally friendly way of protecting banks from erosion. Detailed guidance of these methods is beyond the scope of this Design Guide but should be considered by the design professional.

Erosion repair methods 12 through 16 are NOT recommended. However, they may be necessary when the site is constrained, or where the water volume, velocity, bank steepness, and resultant erosive forces necessitate the use of more extreme methods.

Table 1: Preferred Erosion Repair Methods

Repair Method	Appropriate Slope	Appropriate Water Velocity	Environ Value	Cost
1. Modified floodplain	Varies	Varies	Positive	Low
2. Slope Grading with Vegetation	2:1 or flatter for vegetation section, 1.5:1 or flatter for boulder section.	Low – typically up to 6 ft/sec	Positive	Low
3. Erosion Mats	2:1 or flatter for erosion mat section, 1.5:1 or flatter if boulders used.	Generally 1-7 ft/sec but can go up to 12ft/sec if vegetated.	Positive, if planted.	Low
4. Contour Wattling		Low	Positive	Low
5. Brush Mattresses	2:1 or flatter for erosion mat section, 1.5:1 or flatter if boulders used.	Low	Positive	Low
6. Brush Layering	2:01	Medium	Positive	Low
7. Vegetated Geogrids or Soil Lifts	Up to 1:1	Medium	Positive	Low
8. Root wads and boulders		Medium: (10 ft/sec or less)	Positive, if planted	High
9. Boulder/ Rock Revetment	Up to 1:1, preferably 2:1.	High: up to 15 ft/sec; less where voids in boulders are planted.	Negative. Negative to Neutral, if planted	Medium
10. Cellular Confinement System	Up to 0.5 to 1	Medium to High:5-21 ft/sec depending on vegetation)	Neutral	Medium
11. Live Log Crib Walls	Up to 0.25:1	Medium: up to 12 ft/sec or less	Neutral to High, if planted	High

#1: Modified Floodplain

How to Create a Modified Floodplain

The modified flood plain design provides the optimum solution for long-term, ecologically-friendly, and less expensive stability. In urban areas property owners typically have short stretches of stream running through their property and often only on one side of the stream. The cooperative enlisting of neighbors to affect this approach is well worth the effort. The typical steps in creating a modified floodplain are:

Step 1: Identify the appropriate channel width and depth, at bankfull level. The active channel will contain flows resulting from small frequent rainfall events.

Step 2: Identify the appropriate elevation for the floodplain area, and determine how much space is available and appropriate for widening the banks.

- Step 3: Regrade or lay back the existing bank above the floodplain to a flatter, more stable angle (usually a 2 horizontal to 1 vertical slope, or greater);
- Step 4: Create terraces above the active floodplain to accommodate vegetation
- Step 5: Plant the terraces with appropriate local, native, riparian vegetation to stabilize the bank(s) and create habitat.

How to Create a Modified Floodplain in Deeply Incised Channels

A watershed-friendly design that recreates a natural floodplain is depicted in Figures 4 and 5 below:

Figure 4: Stream channel with deeply incised streambanks

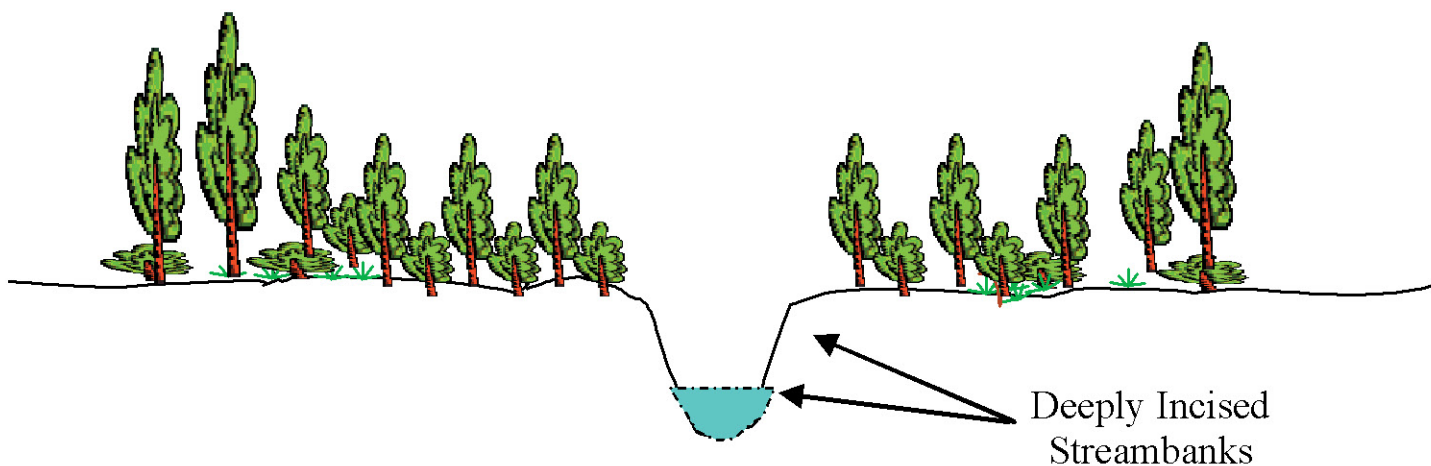
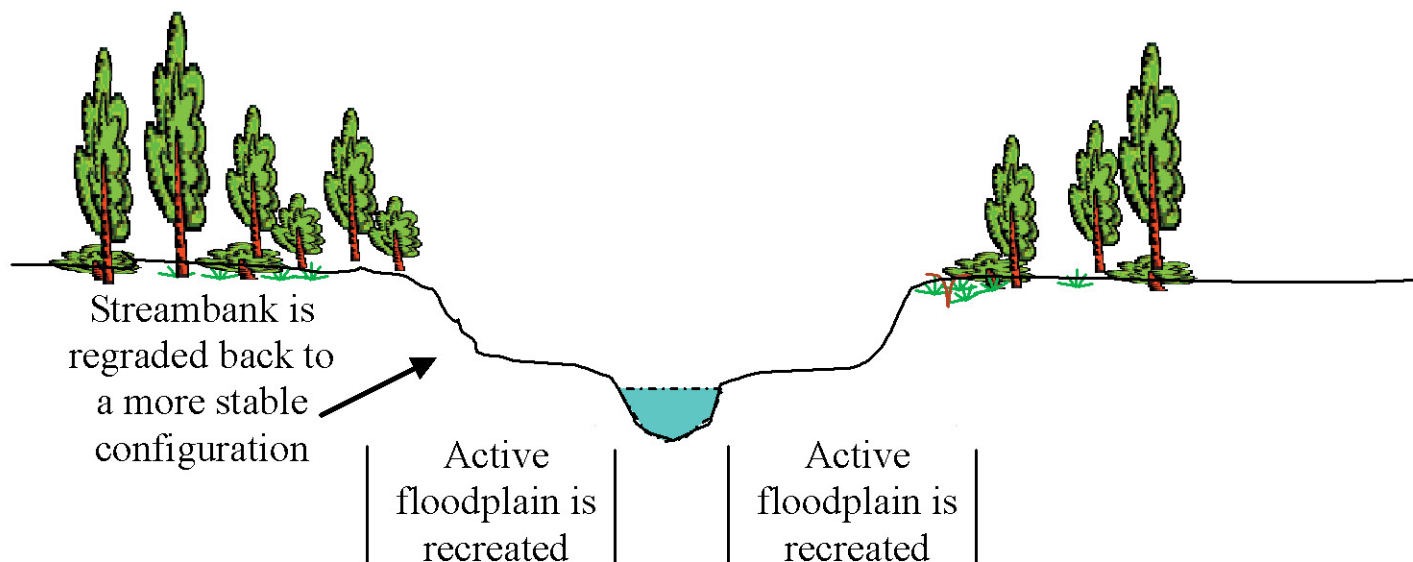


Figure 5: The same stream channel as Figure 4, but stream banks have been regrades to create terraces where vegetation can be planted

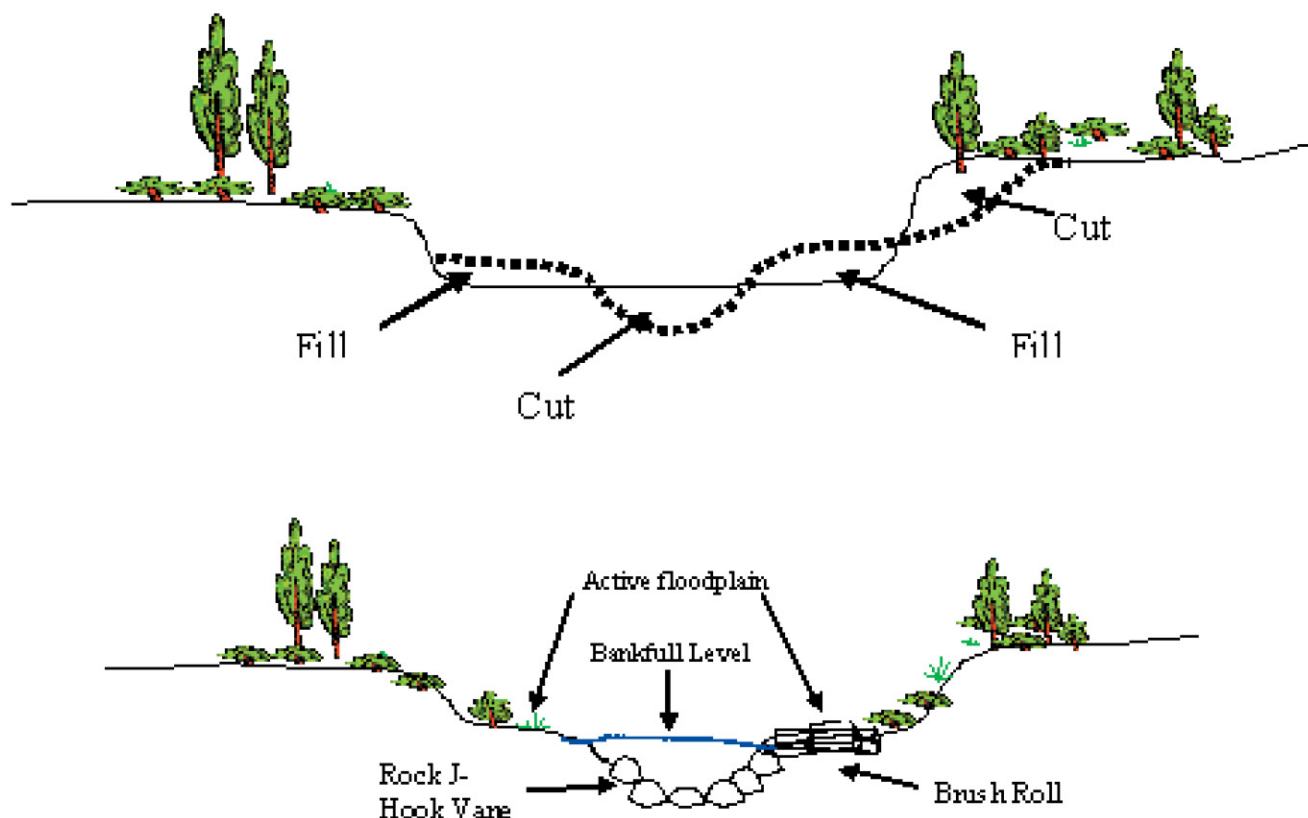


How to Create a Modified Floodplain In Broad Flat Stretches with Sediment Deposition

In some cases, a stream may have experienced heavy sediment deposition over the years. In contrast to the deeply incised channels, with heavy sediment deposition tend to be wide, shallow and rather straight. Although there may have been fish present at one time, the shallow flows make it difficult for them to return. Where there is room, it is important to restore the nature meanders if possible.

Figures 6 below shows a stream prior to a stream restoration project. As you can see, the channel was wide, shallow and rather straight. The bottom drawing shows that the channel was made narrower and constructed with a proper width/depth ratio at the bankfull level. This helped assure the proper transport of sediment through the area by increasing velocities in the active channel. The active channel was moved away from the right bank and into the center of the channel corridor, creating deep pools for steelhead trout and salmon. Brush rolls were used on the top of the right floodplain to accumulate fine sediment and the right vertical stream bank was sloped back and vegetated.

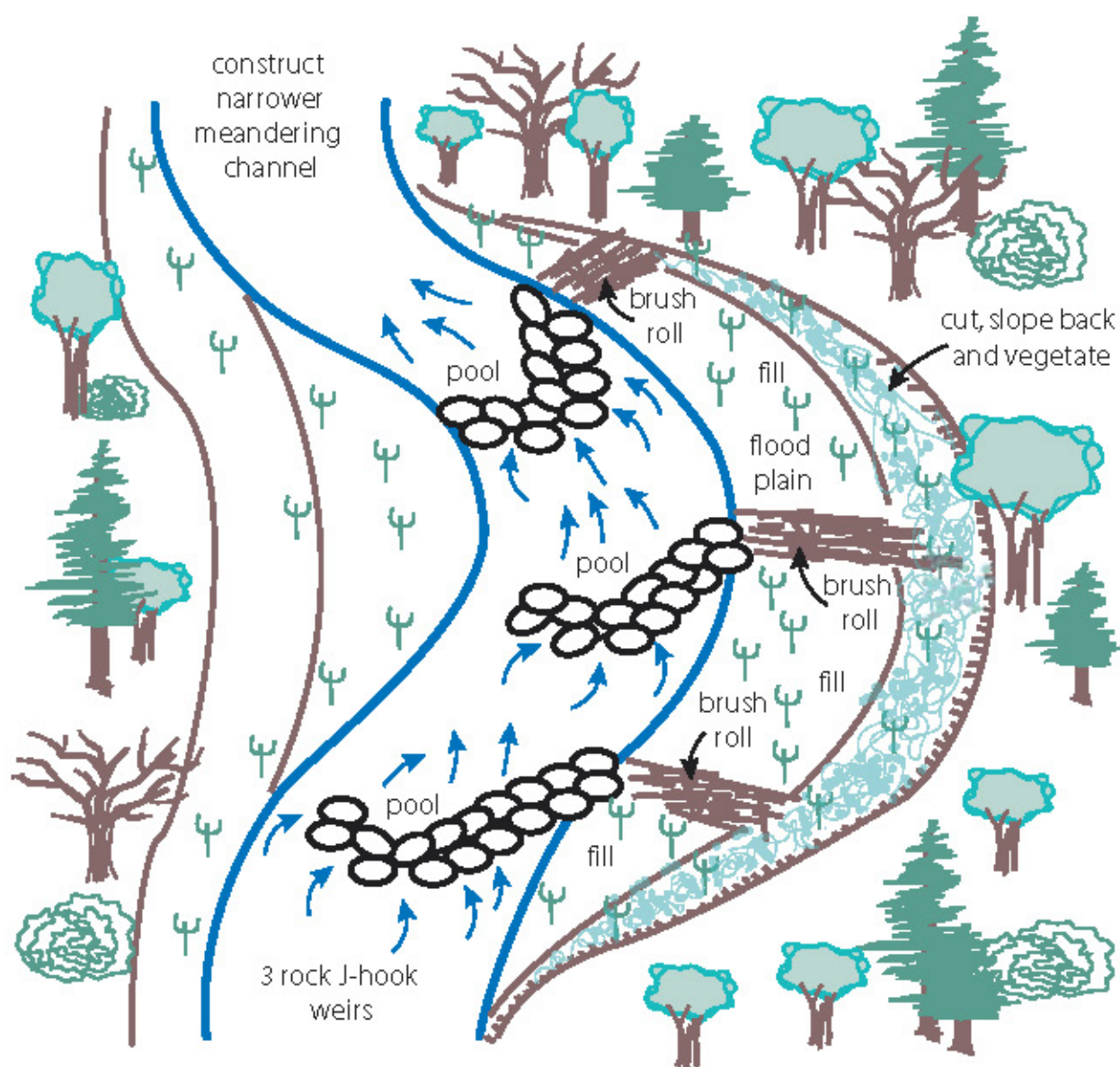
Figures 6: Stream Channel Cross Section View



Possible Variations on the Floodplain Approach

Restoring Natural Stream Meanders

Where there is sufficient room in the stream channel, it can be very helpful to modify the channel in a way that restores natural stream meanders. The diagram below shows how a creek channel can be narrowed and reformed with more meander. As noted earlier, a proper width/depth ratio at the bankfull level is created and a modified floodplain can be constructed. In this example, three J-Hook rock structures were installed with brush rolls on the right bank floodplain to divert the water away from the bank and into the center of the channel.



Additional Toe and Bank Protection for High Flow Velocities or Confined Areas

In the uncommon situations where water velocities are especially high, or where a structure is threatened by its proximity to the bank, additional protection or a hybrid approach may be desired. Placement of rock boulders at the toe of the slope, along with placement of riparian branch cuttings such as willows into the spaces between the boulders into the soil or earth-filled mats can accomplish this goal. Another hybrid approach is to use cellular confinement or rock on the lower slope, and the upper slope can be graded back to a less steep slope and revegetated. The rock must be keyed into the streambed to prevent undercutting and failure of the rock slope protection.

In the cases noted above, the use of bank armoring is likely to cause more problems than it will solve, because it will not address the root cause of the problem. Instead, efforts should be made to reduce the water's velocity, or redirect it away from the bank using j-hook weirs or vanes.

Use of Grade Control Structures

While efforts should be made to construct floodplains/flood benches and to consider hybrid alternatives, it is also important to consider whether a project should be addressed using a grade control structure. For example, sometimes bank erosion is a result of channel bed incision, which increases the height of a bank and reduces vertical support. If a channel is highly incised, simply regrading the slope may not be sufficient in the long-term, and the project will need to address grade control in order to stabilize the bank effectively. A variety of structures can be used, such as log or rock weirs, Newberry weirs, and vanes, in order to encourage sediment deposition and stabilization of the bed.

Use of Deflectors

Finally, in some cases it may be most appropriate to use smaller structures designed to redirect high velocity flow away from eroding banks and into the center of the channel. Examples include spurs, kickers, deflectors, vane dikes, etc., and they should be considered as a way to train flows and reduce the amount of engineered bank protection. The photographs below provide some guidance on how and when these devices can be used. Detailed guidance of these methods, however, is beyond the scope of this Design Guide but should be considered by the design professional.

For a rock cross vane structure, boulders are placed in an upside down "V" shaped structure in the stream. This "V" shaped design serves to slow water velocities near the banks and direct the flow toward the center of the stream. The banks then become depositional areas, instead of erosion areas. At the same time, the increased velocities in the center of the channel actually increase the channel's flow and sediment transport capacity, reducing the risk for infrastructure flooding during high flow events. Finally, the rocks in the center serve as a channel grade control. The drop-off just downstream of the rocks creates a deep hole, which slows flows and can provide an excellent fish hold and hide habitat even at very low flows.

The rock J-hook structure is used to protect one side of the river bank by directing flows from that side to the center of the stream. As with the rock cross vane structure, the increased velocities in the center of the channel increase the channel's flow and sediment transport capacity and the deep hole is created for fish habitat.

Additional Toe and Bank Protection for High Flow Velocities or Confined Areas

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Photograph 1: Rock Cross Vane Structure:



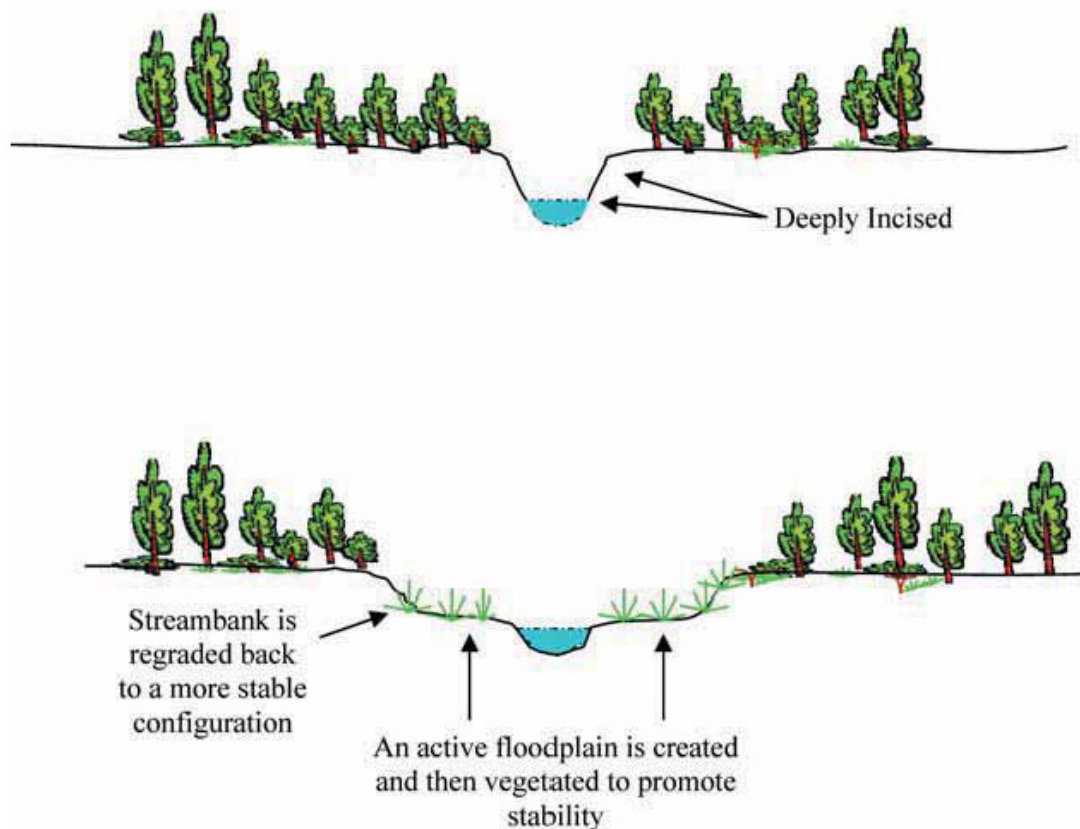
Photograph 2: Rock J-Hook Structure:



How to Create a Modified Floodplain In Broad Flat Stretches with Sediment Deposition

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Figures 6a and 6b below shows a stream prior to a stream restoration project. As you can see, the channel was wide, shallow and rather straight. The bottom drawing shows that the channel was made narrower and constructed with a proper width/depth ratio at the bankfull level. This helped assure the proper transport of sediment through the area by increasing velocities in the active channel. The active channel was moved away from the right bank and into the center of the channel corridor, creating deep pools for steelhead trout and salmon. Brush rolls were used on the top of the right floodplain to accumulate fine sediment and the right vertical stream bank was sloped back and vegetated.



#2: Slope Grading with Vegetation and Floodplain Terraces Space Permitting

This is perhaps the least engineered, and often most effective, method of long-term bank repair, because it restores the natural contour and vegetative cover of the stream bank. If the bank is undercut or has slumped to a vertical face, consider matching the grade of a nearby stable slope. Usually a 2 horizontal to 1 vertical slope is considered stable for many soil types, and if space allows, a 3

How to Create a Modified Floodplain In Broad Flat Stretches with Sediment Deposition

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Figures 6 below shows a stream prior to a stream restoration project. As you can see, the channel was wide, shallow and rather straight. The bottom drawing shows that the channel was made narrower and constructed with a proper width/depth ratio at the bankfull level. This helped assure the proper

Figure 9a: Slope Grading with Vegetation

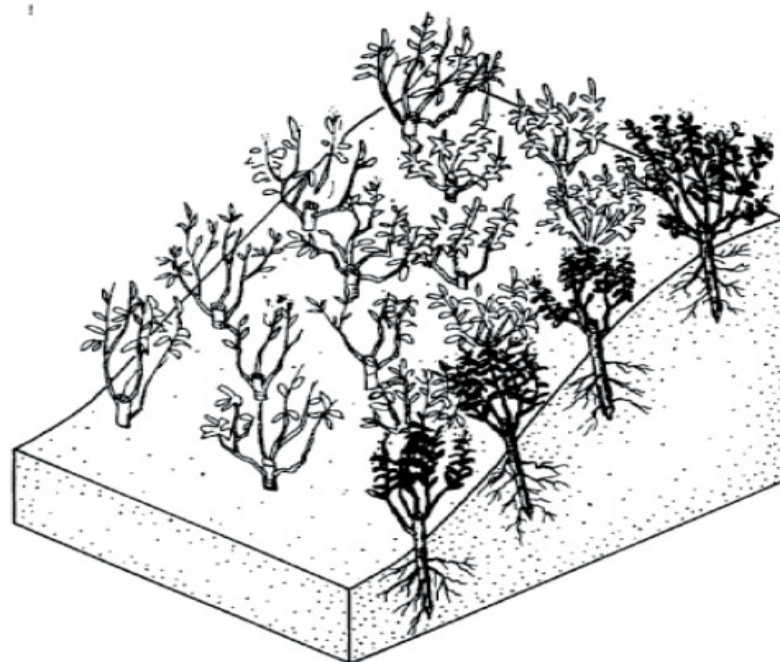
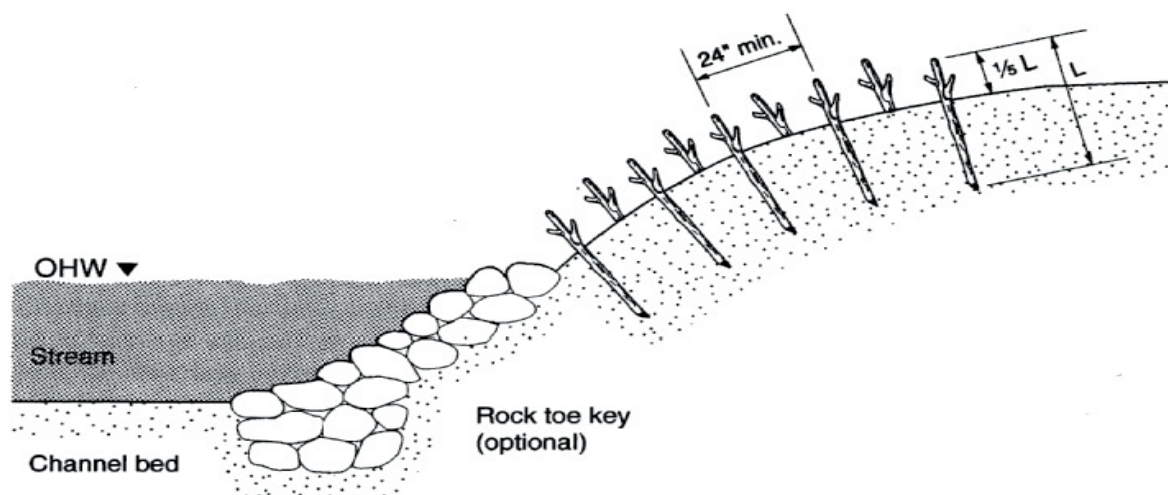


Figure 9b: Cross Section of Slope Grading with Vegetation and Rock Toe Protection



(for definitions and diagrams of bankfull and other terms, see page 5)

#3: Erosion Mats

This method consists of securing geotextile blankets made of biodegradable materials like jute or coconut fiber to channel banks using stakes or staples. Biodegradable fabrics are preferable to plastic because they do not inhibit plant growth, or act like a net if they are dislodged during a storm. The erosion mats provide soft armor protection against erosive forces and are combined with live staking and direct seeding. Abrasive sediment, debris, foot traffic, and sunlight will slowly wear, snag, and tear these fabrics, potentially undermining the structure. That's why erosion mats are intended to be only the foundation of a *vegetated* erosion control system. In other words, the establishment of vegetation is crucial to the long-term success of erosion mats.

Design Considerations:

- Toe protection may be required where significant toe scour is anticipated.
- The bank must be smooth before installing blankets to ensure adequate contact and prevent subsurface erosion.
- The erosion mats must be installed according to manufacturer's instructions in order to prevent failure.

#3a: Erosion Mats with Boulder or Log Toe Protection

This method consists of grading the lower portion of the eroded slope at a maximum of 1.5:1. The upper portion of the slope is then graded at a minimum slope of 2:1 and smoothed to ensure that the whole erosion mat contacts the soil. Appropriately-sized boulders are placed at the toe of the rebuilt bank up to the bankfull discharge water elevation, or even slightly higher. Voids between the boulders can be planted using live stakes.

Design Considerations:

- Best for bank slopes of 3:1 or steeper
- Boulders must be keyed in (min. 3 feet) at the toe of the bank.
- Boulder placement must not constrict the channel cross section or reduce the width-to-depth ratio. Otherwise, the repair will likely destabilize the channel.
- The placement of boulders or armoring along the bank may increase turbulence in the area and other areas downstream. This could increase erosion.

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#4: Contour Wattling (Fascines)

This method consists of tying long bundles of plant cuttings (typically willows or cottonwood) together with twine and anchoring them in shallow trenches, parallel to the stream, with wooden stakes. When the cuttings develop root systems and mature, the plants provide structural soil stability. This technique is generally used to manage surface erosion. It works well in straight stream sections and wherever flow velocity is low.

Design Considerations:

- The long bundles trap and hold soil on banks by creating small, dam-like structures, effectively segmenting the slope length into a series of shorter slope lengths.
- This method enhances the opportunities for locally native species to colonize and therefore should, where appropriate, be used with other soil bioengineering systems and live plantings.
- Reinforcement at the toe of bank may be a limiting factor.
- Contour wattling does not work well in locations where slopes are undergoing geotechnical failure.

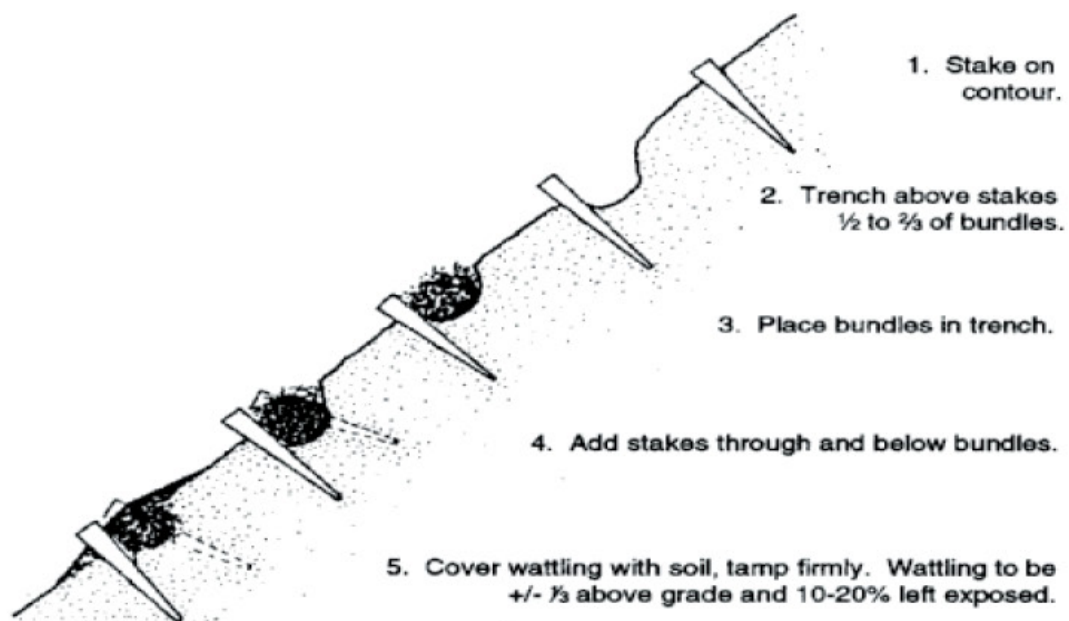
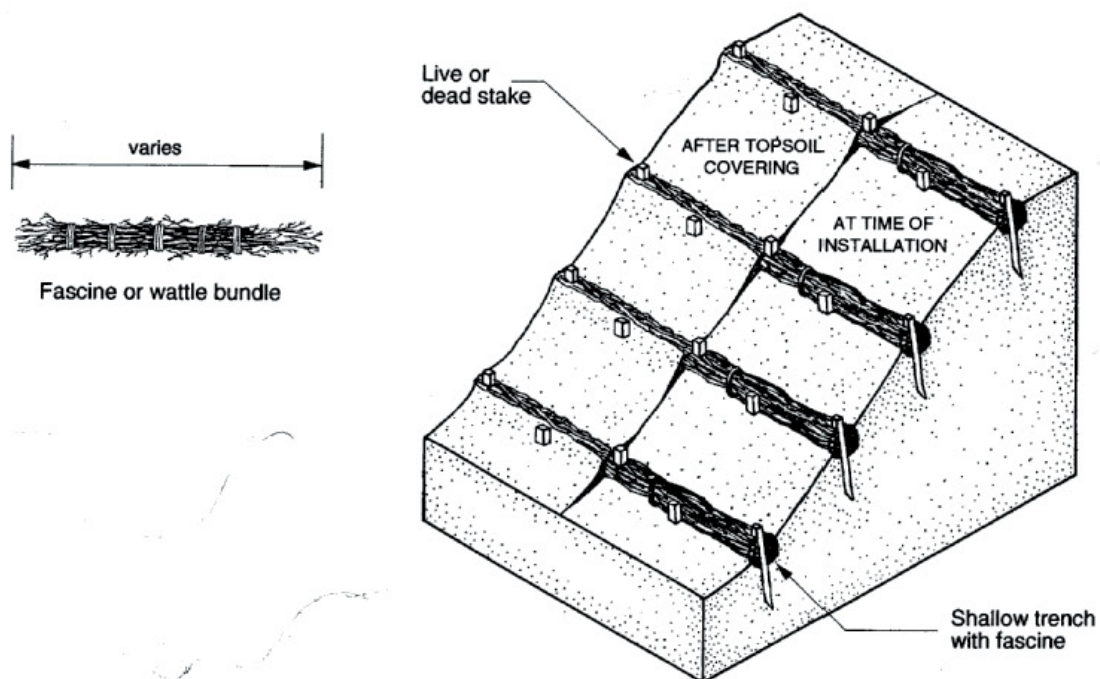
#4a: Contour Wattling with Boulder or Log Toe Protection

Appropriately-sized boulders are placed at the toe of the rebuilt bank up to the bankfull discharge water elevation or slightly higher. Voids between the boulders can be planted using live stakes.

Design Considerations:

- Boulder placement must not constrict the channel cross-section or reduce the width-to-depth ratio. Otherwise, the repair will likely destabilize the channel.
- The placement of boulders or armoring along the bank may increase turbulence in the area and other areas downstream, which could increase erosion.

Figure 10: Contour Wattling



#5: Brush Mattress

First, the bank must be prepared. The eroded slope is graded and smoothed to ensure that all willows are in contact with the soil. Then, a deep trench (2 ft. min) is dug at the toe of the bank for the butt ends of the willow branches. Wood, steel, or live willow stakes are partially driven into the soil in rows, on three foot centers, in the area that will be covered by the mattress. After the stakes have been placed, live willow branches are put on the bank with their butt ends in the trench. Straight branches no shorter than four-feet in length and .5 to 1" in diameter are used. If the branches are not long enough to reach the upper end of mattress, several layers may be used; however, it is necessary to "shingle" the layers by lapping each new layer over the one below by at least 18".

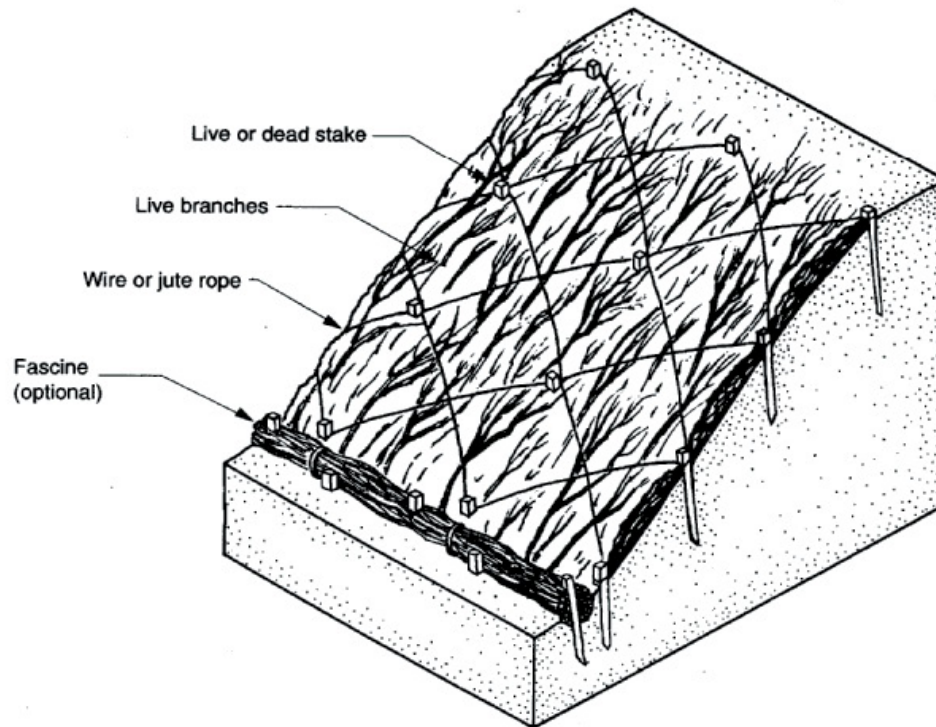
Once the bank is covered by a thick layer of willows, cross branches are placed horizontally over the bottom layer. These branches are placed against the stakes and then tied to the stakes using wire or string. The stakes are then driven into the bank at least two feet deep. After the completion of the mattress, the toe trench is filled with appropriately-sized boulders and rocks to anchor the butt ends of the branches. The brush mattress should be covered with an amount of soil sufficient to ensure a good contact surface between the mattress and the soil, leaving some buds and twigs exposed.

This method forms an immediate protective cover over the stream bank, captures sediment during flood flows, and rapidly restores riparian vegetation and streamside habitat. This measure is not appropriate where toe scour is anticipated, in which case boulders may need to be added at the toe.

Design Constraints and Considerations:

- Branches should be tamped down before tying to create a good contact surface between the soil and the mattress.
- Butt or basal ends of branches must be covered with soil so they can root and to prevent them from drying out.
- Branches should be partially covered with soil.
- **This method should not be used on slopes that are experiencing geotechnical failures or other slope instability.**

Figure 11: Brush Mattress



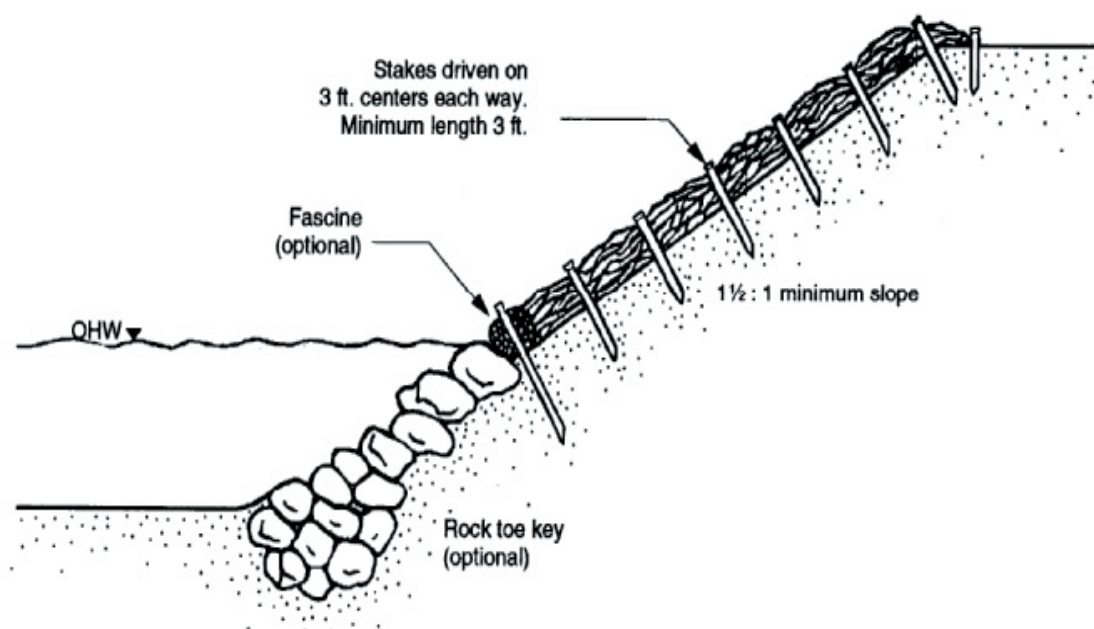
#5a: Brush Mattress with Boulder or Log Toe Protection

First, the lower portion of the eroded slope is graded at a maximum slope of 1.5:1. Then the upper portion of the slope is graded at a minimum of 2:1 and smoothed to ensure all willows are in contact with soil. Appropriately-sized boulders are placed at the toe of the rebuilt bank, up to the bankfull discharge water elevation or even slightly higher. Live stakes can be placed between the boulders to establish vegetation. This method requires a lot of branches. Therefore, needs to be installed during low flow conditions so that growth can be established. Otherwise, the branches will wash away.

Design Criteria:

- Boulders must be keyed in (min. 3 feet) at toe of bank.
- Boulders placement must not constrict the channel cross-section or reduce the width-to-depth ratio. Otherwise, the repair will likely destabilize the channel.
- The placement of boulders or armoring along the bank will increase turbulence in the area and downstream, which could cause increased erosion.

Figure 12: Brush Mattress with Boulder or Log Toe Protection



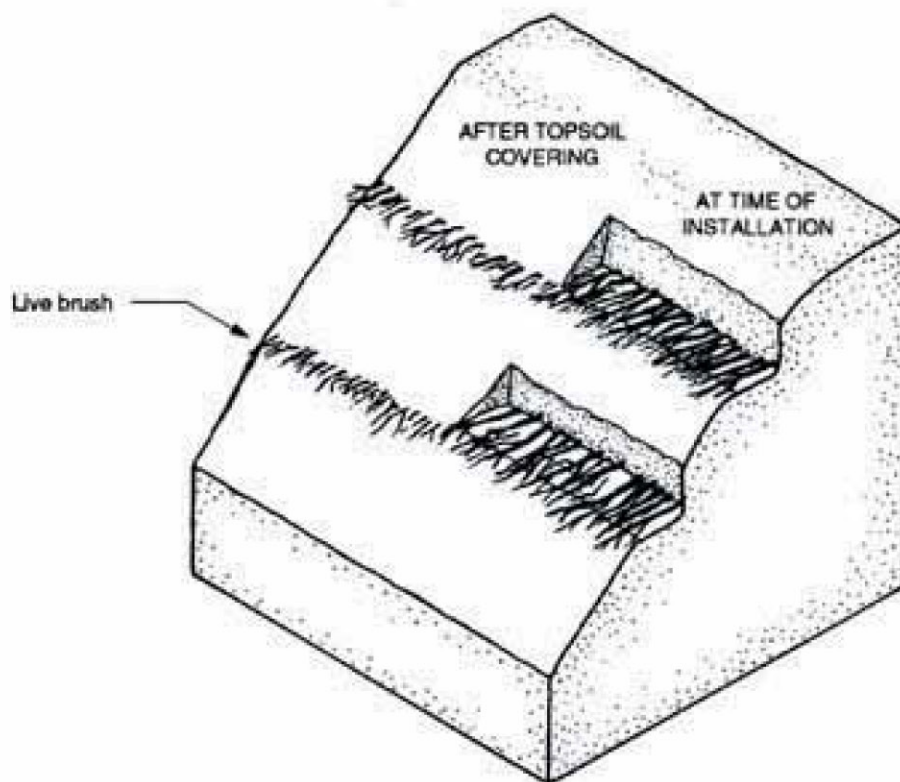
#6: Brush Layering

In this method, alternating layers of soil and live branches are installed in horizontal rows on the streambank. This method is more substantial than brush mattresses and can be used to repair erosion gullies, scour holes, and other significantly scoured areas. The buried branches take root to reinforce the substrate, while the tips produce vegetative top growth that protects the bank surface. This method can also be used in combination with a rock toe, vegetated geogrid or live cribwall as described later in this section.

Design Constraints and Considerations:

- Installation is best done during dry periods or low flow conditions since construction requires earthwork.
- A large amount of branches are needed for this method.

Figure 13 : Brush Layering



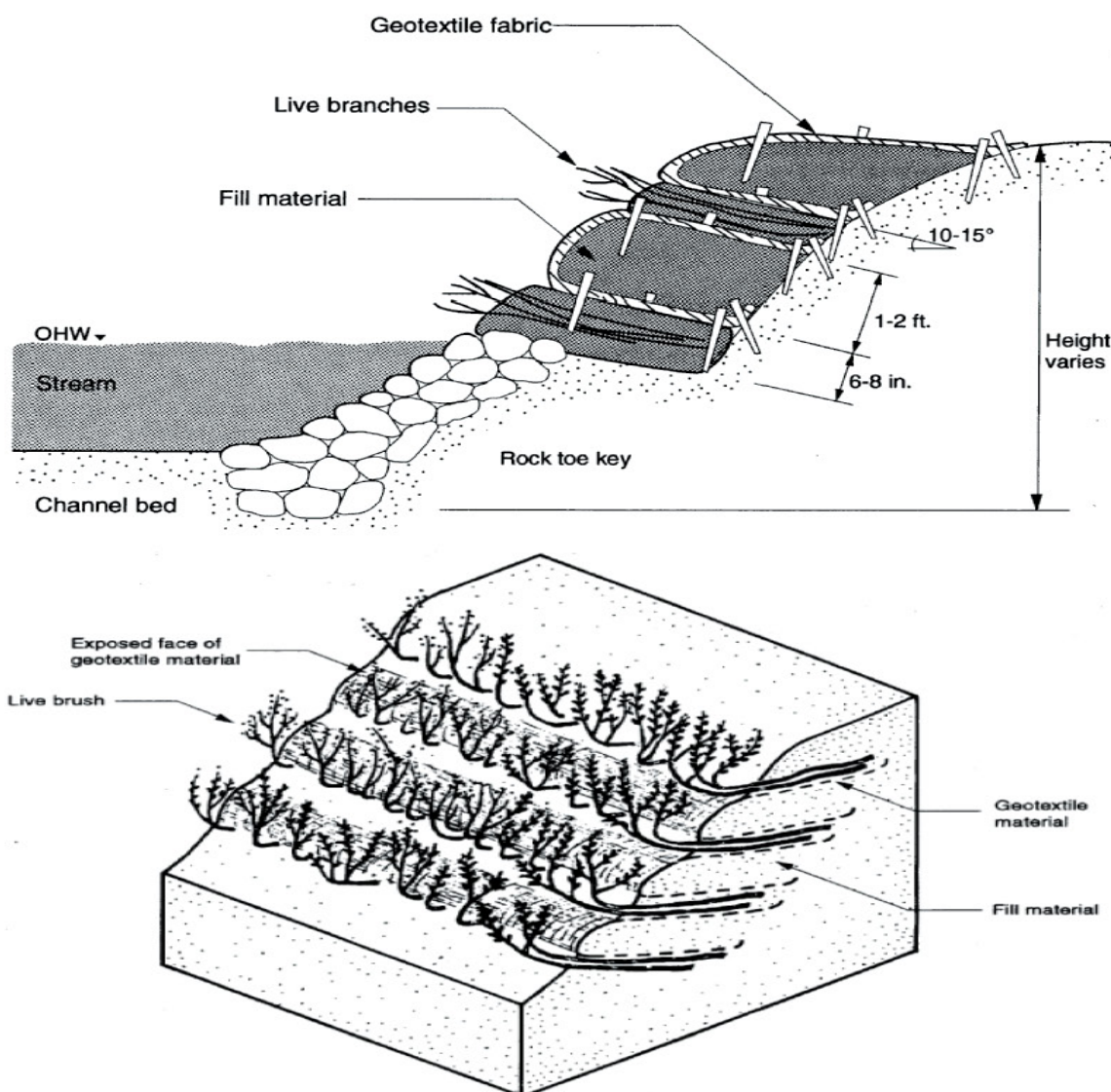
#7: Vegetated Geogrids or Soil Lifts

This method is similar to brush layering, but adds even more stability by wrapping engineered soil lifts in biodegradable erosion control fabric or geotextiles between layers of live branches. This method is useful where site constraints don't allow the slope to be laid back. Boulder or log toe-protection can also be incorporated into the design where site conditions warrant.

Design Considerations:

- Boulder placement must not constrict the channel cross-section or reduce the width-to-depth ratio. Otherwise, the repair will likely destabilize the channel.
- Armoring or the placement of boulders along the bank will increase turbulence in the area and other areas downstream, which could increase erosion.

Figure 14: Vegetated Geogrids or Soil Lifts



#8: Root Wads and Boulders

This method consists of using a combination of boulders, logs, and live plant material to armor a stream bank. It enhances fish habitat, and creates a natural-looking bank stabilization structure¹. Footer logs are set in a toe trench below the thalweg line (the line of maximum depth in a stream), 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 together using boulders, re-bar or cables. Large boulders are placed on top and between the logs at each apex. After all the logs and boulders are set in place, live plant material, such as willows, is placed within the spaces of the structure behind the boulders. Excavated gravel and stream materials can then be placed over the bank end portion of the structure¹.

This method will tolerate high boundary shear stresses if logs and root wads are well anchored. This method should, where appropriate, be used in conjunction with soil bioengineering or live vegetation plantings in order to stabilize the upper bank and ensure a regenerative source of streambank vegetation. The endurance of the structure depends on the species of logs used; it might need replacement if vegetative colonization does not take place.

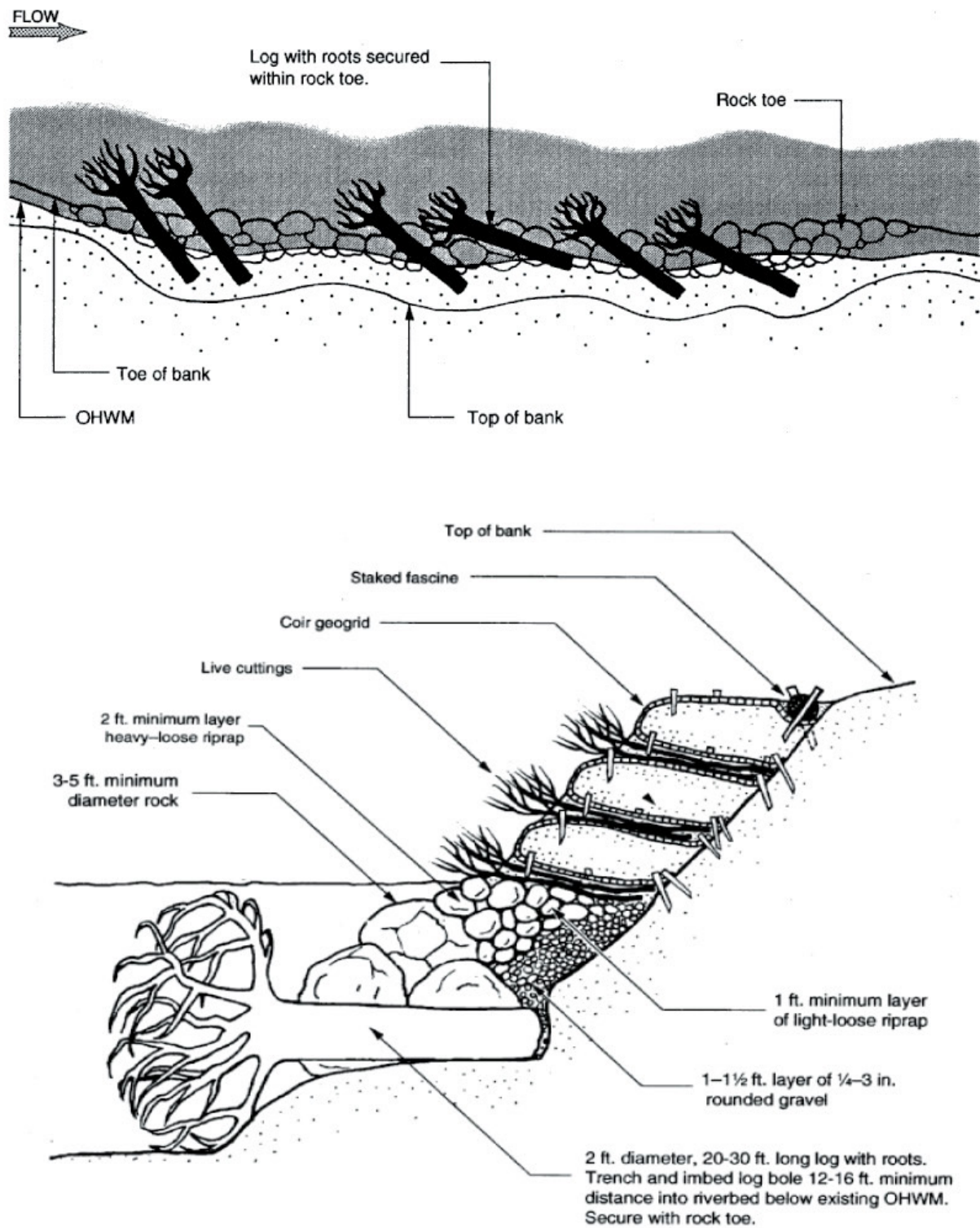
Design Considerations:

- This method may cause channel scour and erosion of downstream and opposite banks if a modified floodplain is not constructed along the opposite bank. It may also cause upstream scour.².

¹Source: California Department of Fish and Game, *California Salmonid Stream Habitat Restoration Manual*

²Source: Natural Resources Conservation Service, *Stream Corridor Restoration Principles, Processes and Practices*

Figure 15: Root Wads and Boulders



#9: Boulder/Rock Revetment

Rock rip-rap is a method for armoring stream banks with boulders that prevent bank erosion. Rock riprap can be used at the toe of the slope in combination with other vegetative methods on the upper portions of the bank. Rock can also be used for drainage outfall structures. Rip-rap footing is laid in a toe trench dug along the base of the bank. The size of the rock is determined according to the expected velocity in the channel, and can vary from 6" to 18" for velocities up to 10 feet per second up to 24" minimum for higher velocities. Large angular boulders are best suited for this purpose because they tend to interlock. The rock's specifications must meet certain standards in order to assure that it is structurally sound.

A gravel blanket that is at least one foot thick should be placed under the rock rip-rap on slopes of 1:1 or greater. This prevents underlying soil from being washed out, which leads to slope slump and failure during periods of high flow. Geotextile fabrics should be avoided, since they prevent the natural establishment of vegetation¹.

This method should, where appropriate, be used with soil-bioengineering systems, or live vegetation, to stabilize the upper bank and ensure a regenerative source of streambank vegetation. A major benefit of this method is that the components are flexible and their function is not impaired by slight movement from settlement or other adjustments².

Design Criteria and Considerations:

- Rock should be keyed in approximately three feet below the bed elevation.
- Rock can be graded from larger at the toe to smaller at the upper banks.
- This method may cause channel scour and erosion, especially downstream and along opposite banks, if a modified floodplain is not constructed along the opposite bank. It may also cause upstream scour.

#9a: Boulder Revetment with Soil and Revegetation

This method consists of placing soil over the boulders and installing vegetation by staking and/or direct seeding. Biodegradable erosion control mats are placed over the soil to help control erosion until vegetation establishes itself. Special care must be taken while driving live stakes between boulders to avoid damage to the cambium layer of the woody material and to ensure good soil/water/stake contact. Thick rip-rap layers may require special tools for establishing staking pilot holes.²

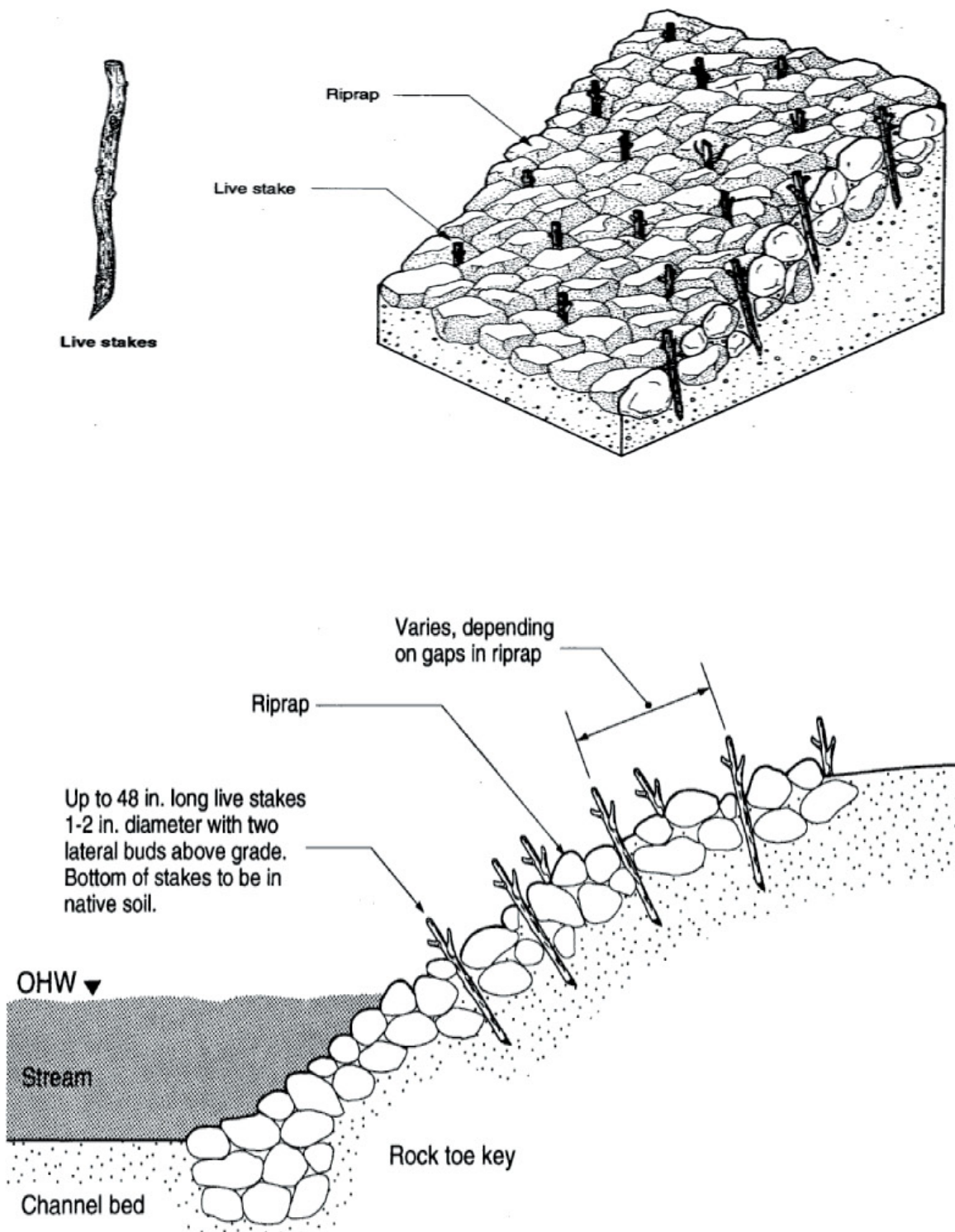
Design Considerations:

- Woody material can be placed using a backhoe with an auger attachment, or by driving a steel bar between boulders, or by placing rock around durable planting tubes.
- This method may cause channel scour and erosion of downstream and opposite banks if a modified floodplain is not constructed along the opposite bank. It may also cause upstream scour.

¹Source: California Department of Fish and Game, *California Salmonid Stream Habitat Restoration Manual*

²Source: Natural Resources Conservation Service, *Stream Corridor Restoration Principles, Processes and Practices*

Figure 16: Boulder Revetment with Soil and Revegetation



#10: Cellular Confinement System

Soil cellular confinement system (geocell) is a polyethylene plastic cellular system where structural strength is developed by the composite design of soil, plant roots, and the plastic's cellular configuration. This system is available in eight-inch deep honeycomb mats that can be installed in offset vertical layers to create terraced planting areas. The honeycomb cells are filled with soil, moderately compacted, and planted with woody vegetation and grasses. The structure functions similarly to a crib wall structure. This method can also be used in combination with slope grading and vegetation on the upper slopes.

This method can foster the development of vegetation.

11: Live Log Crib Walls

Live log crib walls are used to reduce sediment input and protect banks in areas where logs are available and boulders are not practical¹. These temporary structures are designed to rot and degrade after live plant material has established itself. Cribbing provides protection in areas with near-vertical banks where bank sloping options are constrained by adjacent land uses.

In this method, two rows of base logs are placed parallel to the bank, in trenches below stream grade, to minimize undercutting of the structure. Tie-back logs are notched into the base logs and placed at regular intervals (typically 6 to 8 feet) along the base logs. Tie-back logs are attached to the base logs using re-bar pins or cables. There should be at least two tie-back logs connecting each pair of base logs. Once the first row of tie-back logs has been connected, a second set of face logs is placed on top of the tie-backs. This procedure is repeated until the desired level of bank protection is achieved. As each lift is constructed, the face logs and tie-backs 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; but there should be sufficient fine-grain material to insure vegetation growth. Live cuttings are then laid in to form a complete cover layer. These live branches should be long enough to have their butt ends in the soil behind the crib wall. The tips should stick out of the crib wall no more than a quarter of the cutting total length. The branches are then covered with the gravel/cobble mix to the top of the tie-backs, and the next layer is continued.

This method is effective on the outside of bends where high velocities are present, and in situations where a low wall may be required to stabilize the toe and reduce slope steepness². The use of crib walls in a specific location must be considered carefully in the context of the stream's function. If placed incorrectly relative to the active channel, the bends in a meandering stream can induce considerable damage downstream or on the opposite bank. This method does not adjust to toe scour and should be used in combination with soil bioengineering systems and live plantings to stabilize the upper slopes².

Design Criteria and Considerations:

- This method may cause channel scour and erosion of downstream and opposite banks if a modified floodplain is not constructed along the opposite bank. It may also cause upstream scour.
- As the logs rot, the crib wall can be undercut and eventually fail. If the structure fails, hazardous rebar and steel cable can be deposited in the river along with the logs and other debris of the structure.

¹Source: California Department of Fish and Game, *California Salmonid Stream Habitat Restoration Manual*

²Source: Natural Resources Conservation Service, *Stream Corridor Restoration Principles, Processes and Practices*

form mats that can be laid on the channel slope and/or channel bottom.

Figure 17: Live Log Crib Walls

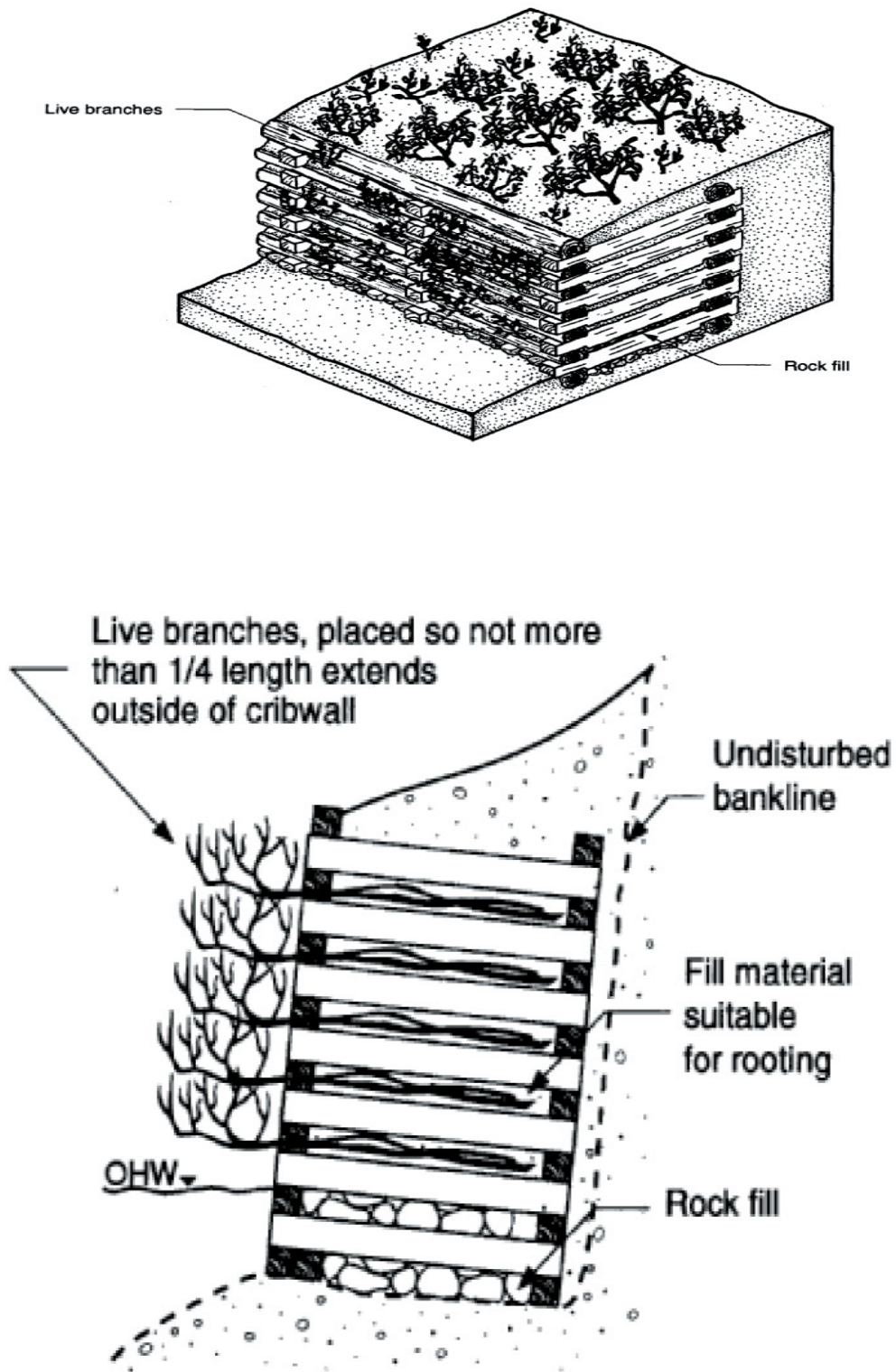


Table 2: Erosion Repair Methods that are NOT Recommended:

Repair Method	Appropriate Slope	Appropriate Water Velocity	Environ Value	Cost
12 Concrete Crib Walls	Up to 0.25:1	High: up to 15 ft/sec; depending on size of crib wall openings.	Negative	High
13: Articulated Concrete Blocks	Up to 1:1	High: up to 15 ft/sec; for closed cell ACBs, low to medium for open cell ACBs.	Negative	High
14: Gabions	From 0.75:1 up to 3:1	High: up to 15 ft/sec; lower velocity if planted, depending on size and number of planting pockets.	Negative	High
15: Sacked Concrete	Up to 0.5:1	High: up to 15 ft/sec;	Negative	High
16: Guniting Slope Protection	Up to 1:1.	High: up to 15 ft/sec	Negative	Medium

#12: Concrete Crib Walls

Concrete crib walls consist of stacked interlocking concrete frames that form a retaining wall. Its structural strength is due in part to the composite design of a concrete frame with compacted backfill. Crib walls are constructed with open face panels that are planted by live staking. This method restricts plant growth to the size of the panel opening. As the crib wall slope is flattened and the lattice becomes more open, the vegetation potential increases, and the allowable velocity decreases because of the exposed soil and vegetation. Concrete crib walls perform similarly to live log crib walls. Because the crib wall is a rigid structure, it is more prone to massive failure in the event of undercutting or settlement.

All crib walls tend to cause channel bed and bank erosion both in the immediate area and other areas downstream, and may also cause erosion upstream. Most crib walls eventually fail because they attempt to resolve a symptom of erosion, not its cause. The use of concrete crib walls is discouraged. This method is mentioned only for reference.

13: Articulated Concrete Blocks

Articulated concrete blocks (ACB) consists of concrete interlocking blocks that are cabled together to form mats that can be laid on the channel slope and/or channel bottom.

There are two styles of ACBs: open cell and closed cell. The open cell style allows for vegetation to be recruited into the soil filling each cell. Vegetation growth is restricted by the sizes of the cell openings and by the disconnection caused by the cell walls. In our arid climate, the long-term viability of vegetation within the restricted cell openings is problematic. However, open planting areas can also be constructed into the ACB mats by creating an opening in the mat by removing some of the blocks. The open areas can be revegetated with shrubs and trees. Irrigation is necessary to aid plant establishment.

This method will create channel and bank erosion both down and upstream of protected areas. It is environmentally unfriendly and prone to failure. When it fails, steel cables and stakes hazardously protrude from the mats into the channel. This method is not appropriate for small erosion repair sites, and is discouraged because of the limited potential for biotic resources.

#14: Gabions

This method consists of placing large wire baskets filled with rocks on channel banks, either as mattresses or stacked in layers that resemble steps. Gabions can sometimes naturally revegetate if adequate water and soil are available. Gabions can also be revegetated using planting boxes. (Planting boxes are gabion cells that are left open to bare soil and revegetated with shrubs and trees.) Temporary irrigation may be provided to the planted vegetation in order to aid its establishment. But, wire baskets can deteriorate over time and may be harmful to fish.

Gabions are very hazardous and unfriendly to native fish, especially salmonids, which often try to spawn in gabions below the water line. The basket wire deteriorates quickly, and the fish are injured on the baskets' sharp wire barbs.

Furthermore, the baskets used to line or armor the banks of streams cause bed and bank erosion. They often undercut or fail due to slumping of the soil on which they are constructed. The use of gabions is discouraged and are rarely permitted by the Department of Fish and Game except in extreme situations. The material is included here for information.

#15: Sacked Concrete

Sacked concrete slope protection consists of burlap bags filled with concrete and placed against channel banks. Sacked concrete does not provide any revegetation potential. However, it offers the opportunity to contour walls around existing vegetation such as tree wells.

Sacked concrete should not be used because it causes erosion, degrades water quality, and destroys other beneficial uses. It is included here for reference. There may, however, be extreme circumstances

where site constraints, vertical slopes, and high velocities preclude all other options.

#16: Guniting Slope Protection

Guniting slope protection consists of a pressurized concrete mixture sprayed over an eroded bank. The guniting can be textured, colored, and formed for aesthetics to mimic natural rock. Reinforcing steel may be placed against the bank prior to spraying. This is not an acceptable method of erosion repair, but is included here because it has been successfully used with soil nails to stabilize vertical slopes on upper banks where land use constraints preclude regrading of the slope. Sheet pile retaining walls have been used in a similar manner. Vegetation can be placed on the lower portions of the bank to enhance biotic resources.

Guniting slope protection causes erosion problems, degrades water quality and destroys other beneficial uses. Therefore, the use of guniting slope protection is discouraged and is included here only for reference.