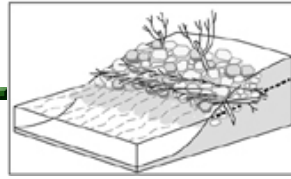


VEGETATED RIPRAP



1. CATEGORY

2.0 – Bank Armor and Protection

2. DESIGN STATUS

Level I

3. ALSO KNOWN AS

Vegetated Rock Revetment, Vegetated Rock Slope Protection (VRSP), Face Planting, Joint Planting

4. DESCRIPTION

Vegetative riprap combines the widely-accepted, resistive, and continuous rock revetment techniques with vegetative techniques. A layer of stone and/or boulder armoring that is vegetated, optimally during construction, using pole planting, brushlayering and live staking techniques.

5. PURPOSE

Continuous and resistive bank protection measures, such as riprap and longitudinal rock toes are primarily used to armor outer bends or areas with impinging flows. The stream energy is resisted by the continuous protection, and is subsequently directed downward into the streambed. This concentration of flow energy will increase scour longitudinally along the toe, and will move the thalweg near the bank toe. These continuous and concentrated high velocity areas will generally result in reduced aquatic habitat. It has been widely documented that resistive techniques, in general and riprap in particular, provide minimal aquatic habitat benefits (Shields et al., 1995). Recently the concerns over the poor aquatic-habitat value of riprap, both locally and cumulatively, have made the use of riprap alone controversial (Washington, 2003).

Since streambank protection designs that consist of riprap, concrete, or other inert structures alone are often unacceptable for lack of environmental and aesthetic benefits, there is greater interest in designs that combine vegetation and inert materials into living systems that can reduce erosion while providing environmental and aesthetic benefits (Sotir, 1997).

The negative environmental consequences of riprap can be reduced by minimizing the height of the rock revetment up the bank and/or including biotechnical methods, such as vegetated riprap with brushlayering and pole planting, vegetated riprap with soil, grass and ground cover, vegetated riprap with willow (*Salix* spp) bundles, and vegetated riprap with bent poles.



Figure 1. Vegetated riprap, using live cuttings, after 3 years. This site had vegetated riprap installed during a training course led by the USDA NRCS. Rouge River, Ford Field, Dearborn, MI. Photo by J. McCullah

Combining riprap with deep vegetative planting (e.g., brushlayering and pole planting) is also appropriate for banks with geotechnical problems, because additional tensile strength is often contributed by roots, stems, and branches. In contrast, trees and riparian vegetation planted only on top of the bank can sometimes have a negative impact (Simon & Collison, 2001).

Correctly designed and installed, vegetated riprap offers an opportunity for the designer to attain the immediate and long-term protection afforded by riprap with the habitat benefits inherent with the establishment of a healthy riparian buffer. The riprap will resist the hydraulic forces, while roots and branches increase geotechnical stability, prevent soil

loss (or piping) from behind the structures, and increase pull-out resistance (McCullah, 2004). Aboveground components of the plants will create habitat for both aquatic and terrestrial wildlife, provide shade (reducing thermal pollution), and improve aesthetic and recreational opportunities. The roots, stems, and shoots will help anchor the rocks and resist ‘plucking’ and gouging by ice and debris.



Figure 2. The riprap protection on this important Coho salmon stream, while protecting the banks from future erosion and sedimentation, provides little to no habitat. San Lorenzo River, Santa Cruz, CA. Photo by J. McCullah



Figure 3. Attempt to revegetate the riprap after construction was complete was not cost-effective. Techniques such as pole planting, bent pole method, spurs or LWD structure could have immediate benefits to cover, substrate complexity, and habitat diversity.



Figure 4. Vegetated riprap after construction with pole and brushlayering methods. Note rock spur in foreground designed to increase substrate complexity. Branciforte Creek, Santa Cruz, CA. Photo by J. McCullah



Figure 5. Vegetated riprap at Branciforte Creek after 3 yrs. Note that rock spur provides resting habitat for fishery biologists.

6. PLANNING

Useful for Erosion Processes:

- ✓ Toe erosion with upper bank failure
- ✓ Scour of middle and upper banks by currents
- ✓ Local scour
- ✓ Erosion of local lenses or layers of noncohesive sediment
- Erosion by overbank runoff
- General bed degradation
- Headcutting
- Piping
- ✓ Erosion by navigation waves

- ✓ Erosion by wind waves
- ✓ Erosion by ice and debris gouging
- General bank instability or susceptibility to mass slope failure

Spatial Application:

- Instream
- ✓ Toe
- ✓ Midbank
- ✓ Top of Bank

Hydrologic / Geomorphic Setting

- ✓ Resistive

- Redirective
- ✓ Continuous
- Discontinuous
- ✓ Outer Bend
- Inner Bend
- Incision
- ✓ Lateral Migration
- Aggradation

Conditions Where Practice Applies:

Vegetated Riprap is appropriate where infrastructure is at risk, and where redirective and discontinuous bank protection measures have been rejected or deemed inappropriate (D. Derrick, personal communication, 2002). Vegetative riprap techniques are sometimes considered mitigation for some of the impacts caused by riprap (Washington, 2003). Incorporating large and dense trees may be beneficial where thermal pollution is occurring, along north-facing banks (trees will cast shade) and where cover is necessary to protect fish (rearing habitat).

Complexity:

Moderate. The timing of the construction to coincide the season and climate which maximize the plant establishment can be problematic but usually overcome.

Design Guidelines / Typical Drawings:

While riprap is very effective at arresting bank erosion and providing relatively permanent bank protection the environmental consequences can be less than desirable and should, therefore always be taken into account when selecting an environmentally-sensitive streambank stabilization treatment.

Scour counter-measures are sometimes required for continuous and resistive rock bank protection. One alternative is a rock-filled key trench, designed with appropriate scour analysis. Another counter-measure that may be employed is the use of graded, [Self-Launching Stone](#).



Figure 6. An example of filter material.

Filter Material : Some sort of filter material is typically used to prevent piping of fine soils from below the riprap, if [Self-Launching Stone](#) is not used. There are two choices: filter fabric or graded filter gravel. Filter fabrics are not recommended for use in vegetated riprap, as roots have difficulty penetrating the fabric. If filter fabric is required, one can cut holes in the fabric where the vegetation is placed. Small slits in the fabric are especially appropriate with the bent pole method. This can, however, make placement much more labor-intensive.

Filter gravel is the preferred filter media for vegetated riprap; the following composition is an example of graded gravel that has been successfully used as a filter layer (see Table 1). The composition of all filter blankets should be based on site-specific conditions. Other filter designs can be found in Brown et al, 1998.

TABLE 1. Example Composition of Filter Gravel

Sieve Size	Percentage Passing
25 mm (1 in)	100
19 mm (3/4 in)	90-100

10 mm (3/8 in)	40-100
No. 4	25-40
No. 8	18-33
No. 30	5-15
No. 50	0-7
No. 200	0-3

Rock Size: There are two options for rocks – Self-Launching / Self-Filtering Rock or standard riprap. The advantage of Self-Launching / Self-Filtering rock is that the revetment will build its own toe, by self-launching, in any scour hole that forms. In addition, the different sizes of rock act as their own filter medium, so no filter fabric or filter gravel is needed. This decreases cost, and also makes installation less labor-intensive for two of the three methods of installation. However, using self-launching stone is dependent on a source of graded rock, which is not always available.

Rock sizing guidelines for standard riprap stone are available below in the Hydraulic Loading section.

Commonly Used Vegetative Methods

There are four methods for vegetating riprap that have demonstrated effectiveness:

- Vegetated Riprap with Willow Bundles,
- Vegetated Riprap with Bent Poles,
- Vegetated Riprap with Brushlayering and Pole Planting,
- Vegetated Riprap with Soil Cover, Grass and Ground Cover.

A commonly used method for revegetating riprap is:

- Joint or Live Stake Planted Riprap.



This 'joint planted' riprap was had live willow stakes inserted into the bank during construction which resulted in vigorous growth and complete coverage. Stillwater Creek, Shasta College, CA



Vegetated riprap is aesthetically pleasing, while providing increased bank stability, cover, shade and organic matter. Stillwater Creek, Redding, CA. Courtesy of J. McCullah

Summary of Methods

Vegetated Riprap with Willow Bundles is the simplest to install, but it has a few drawbacks. This technique typically requires very long (3-7m (10-23 ft)) poles and branches, as the cuttings should reach from 15 cm (6 in) below the low water table to 30 cm (1 ft) above the top of the rocks. In addition, only those cuttings that are in contact with the soil will take root, and therefore, the geotechnical benefits of the roots from those cuttings on the top of the bundle may not be realized.

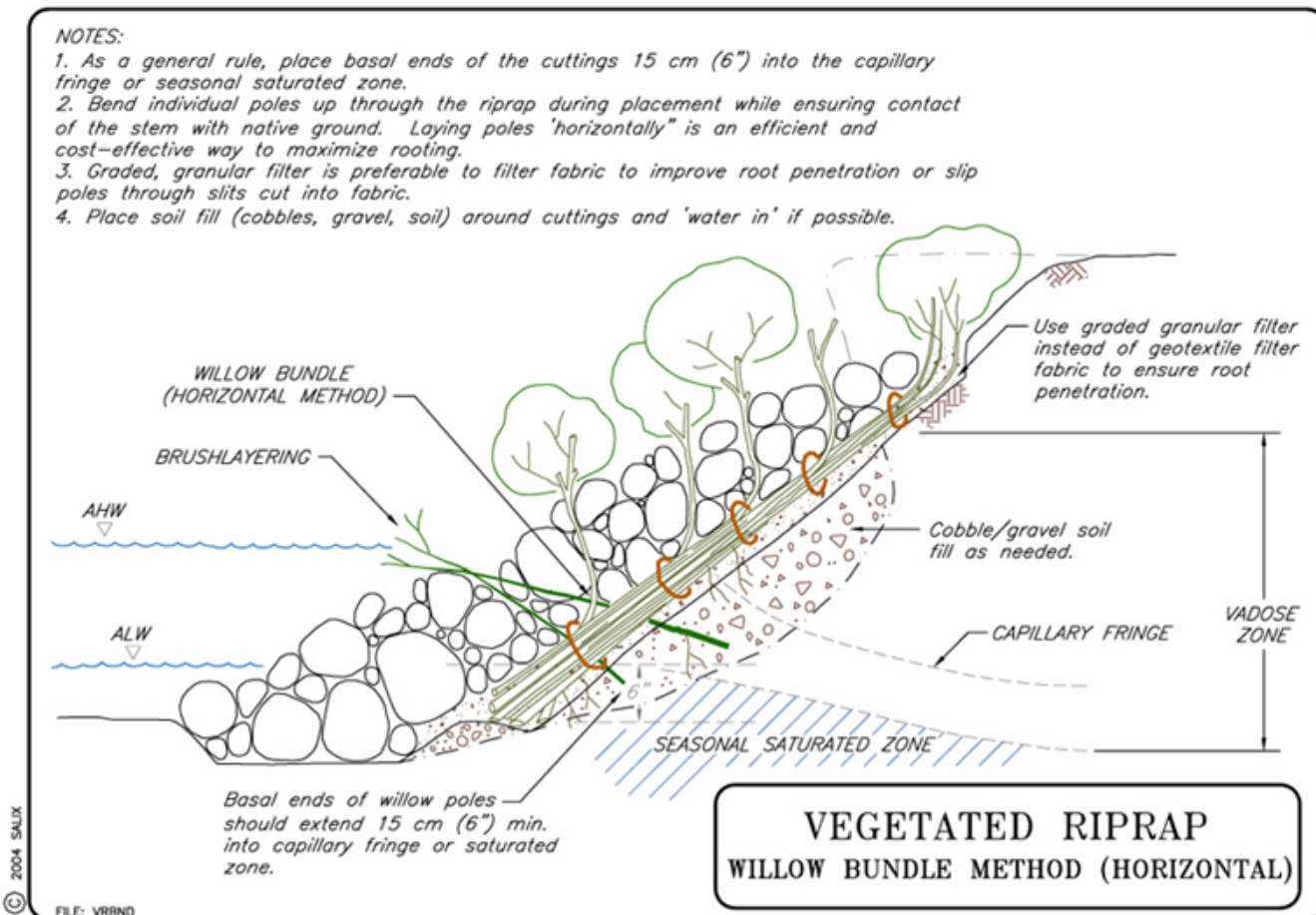
Vegetated Riprap with Bent Poles is slightly more complex to install, however, it is the only method known that can be installed with filter fabric. In addition, a variety of different lengths of willow cuttings can be used, because they will protrude from the rock at different elevations.

Alice Watts Hostetler described the bent pole method in the [June, 1930 issue of American Forests](#),

"Plant live willow logs or poles in trenches in a horizontal or angular position that is in harmony with the slope of a river bank or lakeshore. The angle can be three to one, or forty-five degrees. A tree and root growth will develop the entire length of each pole planted, whether it be five or fifty feet long. Young trees will shoot up to a surprising height in a summer – from three to six feet – and the seeking, spreading roots will go to amazing depths – as far as fifteen feet. It is necessary to use temporary artificial protection to stop erosion until the tree and root growth are advanced sufficiently to resist floods. The kind of protection, varying from brush mats to sand bags and stone riprap, depends on the conditions to be met."

Vegetated Riprap with Brushlayering and Pole Planting is the most complex type of riprap to install, but also provides the most immediate habitat benefits. The installation of this technique is separated into 2 methods; one method describes installation when building a bank back up, while the other is for a well-established bank. If immediate aquatic habitat benefits are desired, this technique should be used. One must bear in mind, however, that vegetated riprap with brushlayering and pole planting may not provide the greatest amount of root reinforcement, as the stem-contact with soil does not extend up the entire slope. Combination of this technique with Pole- or Bundle-Planted Riprap will perform well, as the latter techniques typically have higher rooting success.

Construction specifications have also been provided for the installation of Joint or Live Stake Planted Riprap – this is Revegetated Riprap, as opposed to the other techniques, which are true Vegetated Riprap methods. This technique should be used only when attempting to get vegetative growth on previously-installed riprap.



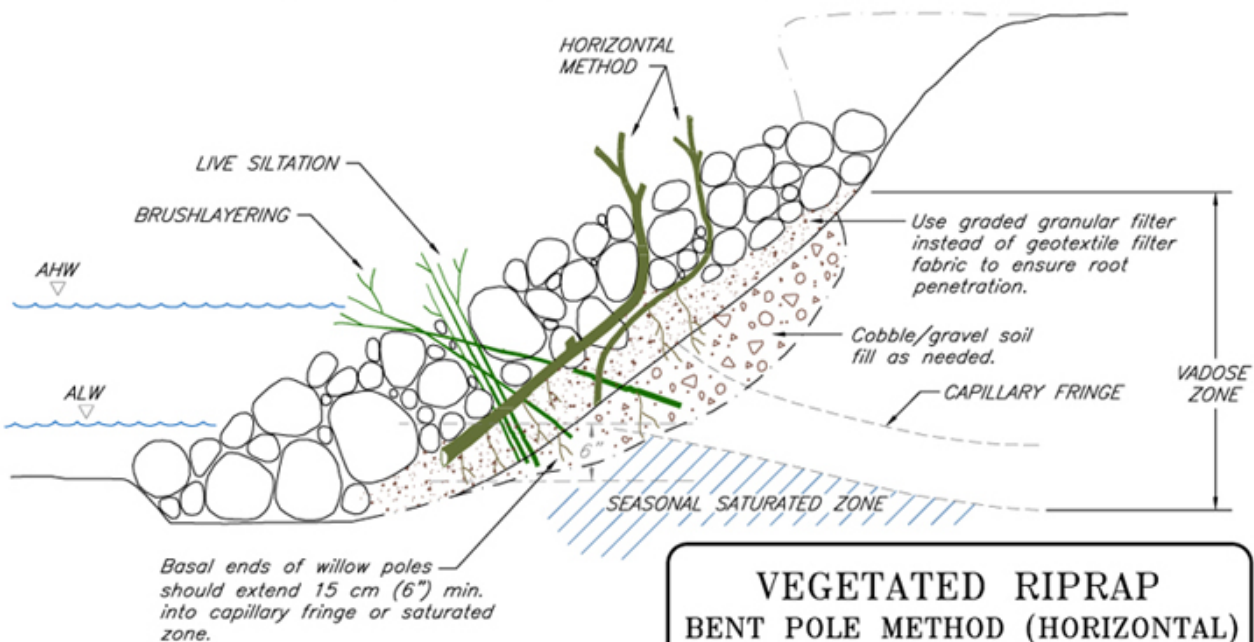
Vegetated Riprap - Willow Bundle Method Typical Drawing

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NOTES:

1. Integrate brushlayering, pole planting and live siltation techniques during rock placement to ensure contact with native ground. Laying poles 'horizontally' is an efficient and cost-effective way to maximize rooting.
2. As a general rule, place basal ends of the cuttings 15 cm (6") into the capillary fringe or seasonal saturated zone.
3. Graded, granular filter is preferable to filter fabric to improve root penetration or slip poles through slits cut into fabric.
4. Place soil fill (cobbles, gravel, soil) around cuttings and 'water in' if possible.



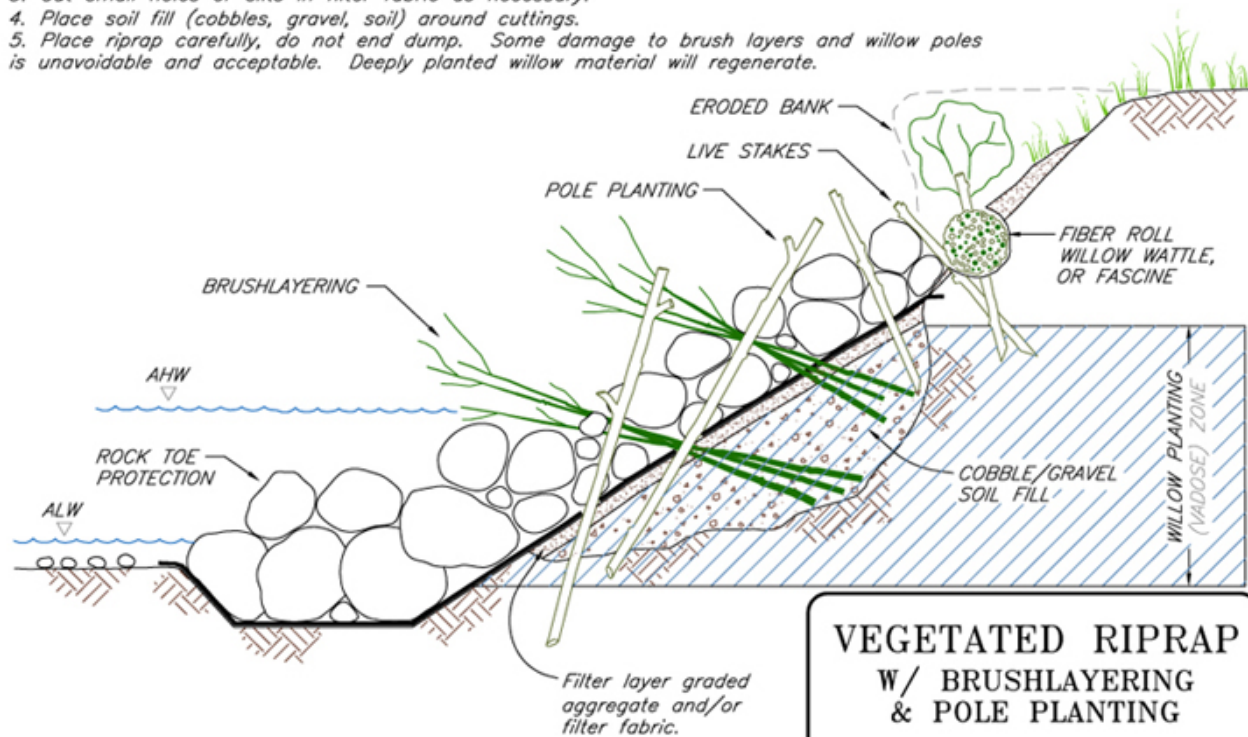
Vegetated Riprap - Bent Pole Method Typical Drawing

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[.dgn](#)

NOTES:

1. Install willow pole planting and brushlayering during bank grading and riprap placement to ensure good contact with 'native ground' and/or soil fill.
2. Willow poles and brush layers should extend down into expected soil moisture zones (vadose).
3. Cut small holes or slits in filter fabric as necessary.
4. Place soil fill (cobbles, gravel, soil) around cuttings.
5. Place riprap carefully, do not end dump. Some damage to brush layers and willow poles is unavoidable and acceptable. Deeply planted willow material will regenerate.



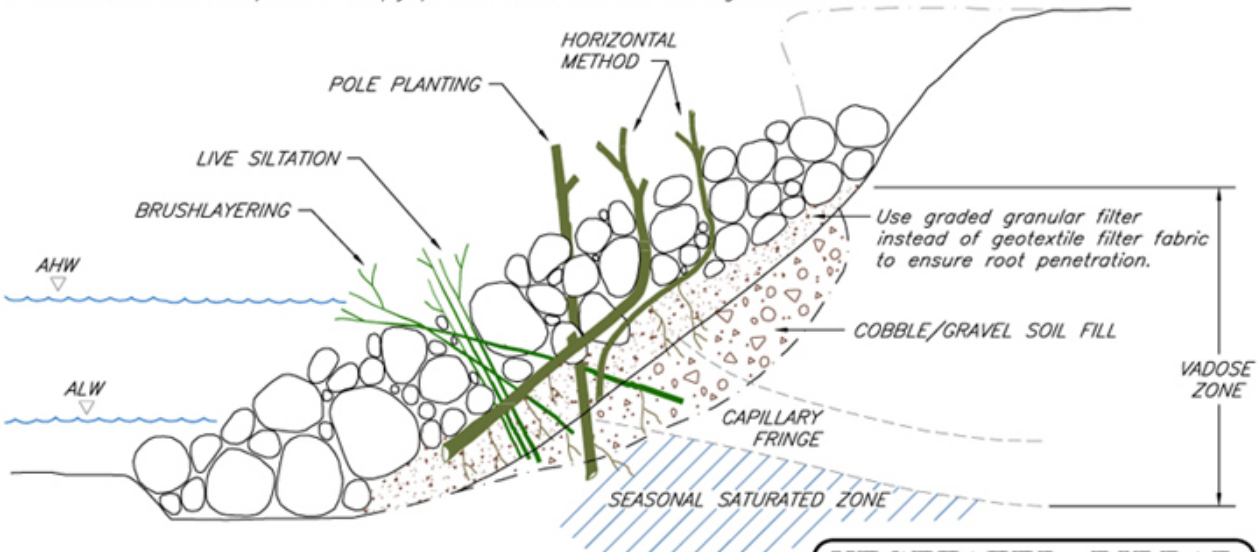
Vegetated Riprap with Brushlayering and Pole Planting Typical Drawing

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NOTES:

1. Integrate brushlayering, pole planting and live siltation techniques during rock placement to ensure contact with native ground.
2. Plant deeply if possible. Place cuttings deeply into vadose zone, into the capillary fringe or 15 cm (6") into the seasonal saturated zone (water table).
3. Graded, granular filter is preferable to filter fabric to improve root penetration or slip poles through slits cut into fabric.
4. Place soil fill (cobbles, gravel, soil) around cuttings and 'water in' if possible.
5. Place riprap carefully, do not end dump. Some damage to brush layers and willow poles is unavoidable and acceptable. Deeply planted willow material will regenerate.



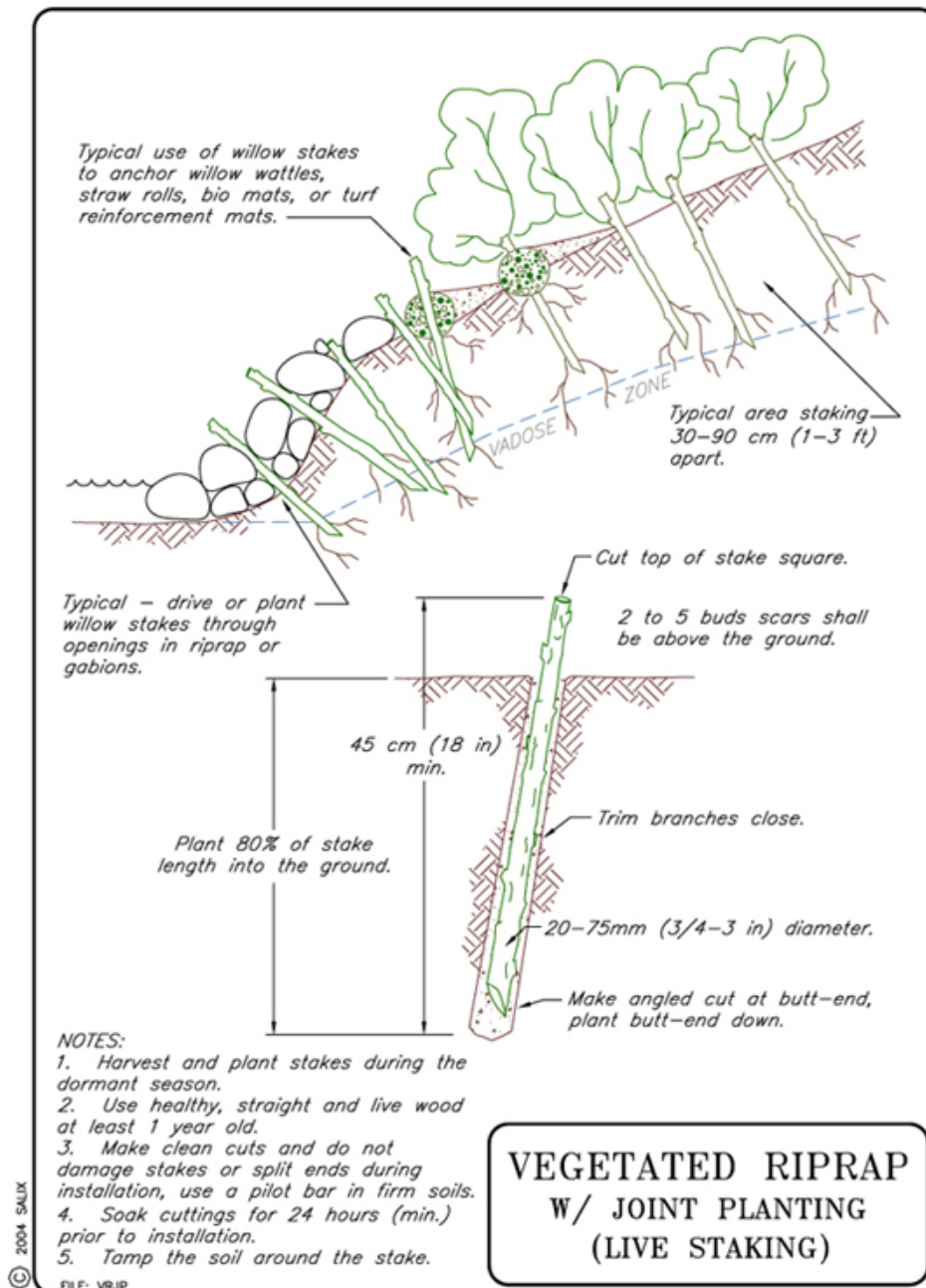
**VEGETATED RIPRAP
DURING CONSTRUCTION
SUMMARY OF TECHNIQUES**

© 2004 SAUX
FILE: VRDC

**Vegetated Riprap During Construction Typical
Drawing**

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**Vegetated Riprap with Joint Planting Typical
Drawing**

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7. ENVIRONMENTAL CONSIDERATIONS / BENEFITS

There are many environmental benefits offered by Vegetated Riprap, most of which are derived from the planting of willows or other woody species in the installation. The willow provides canopy cover to the stream, which gives fish and other aquatic fauna cool places to hide. The vegetation also supplies the river with carbon-based debris, which is integral to many aquatic food webs, and birds that catch fish or aquatic insects will be attracted by the increased perching space next to the stream (Gray & Sotir, 1996). The exclusive placement of predator-perching type habitat may not be appropriate where fish-rearing habitat is desired. In that situation, large rocks and logs located above the AHW might be

replaced with shrubby-type protective vegetation. An additional environmental benefit is due to the use of rock, as the surface area of the rocks is substrate that is available for colonization by invertebrates (Freeman & Fischenich, 2000). The small spaces between the rocks also provide benthic habitat and hiding places for small fish and fry.

The different methods of vegetated riprap provide different environmental benefits. Bundle planted riprap sprouts at the top of the slope, which provides some great terrestrial habitat, but does not benefit the aquatic environment for several years (C. Hoag, personal communication, 2002). The brushlayering methods reach out over the water, and provide shade and organic debris to the aquatic system. Brushlayering can also provide both immediate short-term and long-term water quality benefits. Therefore, when planning a project it is important to determine what environmental benefits are desired. If both terrestrial and aquatic benefits are important, then one should consider interspersing the two techniques along the length of the revetment (C. Hoag, personal communication, 2002).

8. HYDRAULIC LOADING

The riprap blanket should be keyed into the streambed below the expected depth of scour. Toe depth should be based on potential scour, which is not directly related to stream discharge. More stone can be placed as a skirt at the base of the revetment or be used to increase the width of the key; the purpose of this stone being to fall into scour holes should they be deeper than expected (See Technique: [Longitudinal Stone Toe](#), and Special Topics: [Self Launching Stone](#), and [The Key to Stability is the Key](#)).

Permissible shear and velocity for vegetated riprap is related to the size of rock used in construction. Other factors, such as the angularity of the stone, the thickness of the layers of stone, and the angle at which the faces of the stone structure are constructed also come into play. Detailed guidance for sizing stone for bed and bank stabilization structures is beyond the scope of this guideline, and many approaches are available (see Special Topic: [Designing Stone Structures](#)). However, the Maynard (1995) equation gives a D_{50} stone size for an angular stone riprap revetment of 0.875 m (2.87 ft) if the near-bank vertically averaged velocity is 3.5 m/s (11.5 ft/s), and flow depth = 1 m (3.3 ft), and stone is placed on a bank slope of 1V:1.5H. Use of riprap larger than this is unusual.

9. COMBINATION OPPORTUNITIES

Vegetated riprap is often combined with Vegetated Earthen Spurs, [Spur Dikes](#), [Vanes](#), [Bendway Weirs](#), [Large Woody Debris Structures](#), Stone Weirs, [Longitudinal Stone Toe](#), [Longitudinal Stone Toe with Spurs](#), [Live Siltation](#), [Live Brushlayering](#), [Willow Posts and Poles](#), [Vegetation Alone](#), [Live Staking](#), [Live Fascines](#), [Turf Reinforcement Mats](#), [Erosion Control Blankets](#), [Rootwad Revetments](#), [Live Brush Mattresses](#), [Soil and Grass Covered Riprap](#), [Cobble or Gravel Armor](#), [Vanes with J-Hooks](#), [Boulder Clusters](#), and [Newbury Rock Riffles](#).

10. ADVANTAGES

Riprap has many advantages over other types of "hard" revetments (WRP, 1998). When graded or "self-launching" stone is used, riprap is self-adjusting to small amounts of substrate consolidation or movement. The revetment can sustain minor damage and still continue to function adequately without further damage. The rough surface of the riprap dissipates local currents and minimizes wave action more than a smooth revetment (like concrete blocks). Stones are readily available in most locations, and materials are less expensive than many other "hard armoring" techniques. The rock provides a large amount of aquatic habitat. Riprap is easily repaired by placing more rock where needed (WRP, 1998).

It often takes many years for riprap to become vegetated if vegetation is not integrated into its design and construction at the outset. Studies of the Sacramento River revetment performance during the 1986 flood showed that naturally vegetated revetments sustained less damage than unvegetated revetments (Shields, 1991). The fibrous roots of the chosen vegetation prevents washout of fines, stabilizes the native soil, anchors armor stone to the bank, and increases the lift-off resistance. The vegetation also improves drainage of the slope by removing soil moisture for its own use (USDA, 1996). Vegetated riprap has a more natural appearance, and is therefore more aesthetically pleasing, which is frequently a matter of great importance in high-visibility areas. In addition, environmental clearances are frequently easier to obtain if the project has biotechnical and habitat enhancement benefits incorporated into the design.

11. LIMITATIONS

- Vegetated riprap may be inappropriate if flow capacity is an issue, as bank vegetation can reduce flow capacity (see Special Topic: [Management of Conveyance](#)), especially when in full leaf along a narrow channel.
- In remote areas large rocks may be difficult to obtain and transport, which may greatly increase costs.
- Riprap may present a barrier to animals trying to access the stream (WRP, 1998).

12. MATERIALS AND EQUIPMENT

The vegetation obtained should be poles of adventitiously-rooting native species (such as willow, cottonwood or dogwood), with a minimum diameter of 38 mm (1.5 in), and be sufficiently long to extend into the vadose zone below the riprap. See Special Topic: [Harvesting and Handling of Woody Cuttings](#).

13. CONSTRUCTION / INSTALLATION

Vegetated Riprap with Willow Bundles

- Grade the bank to the desired slope where the riprap will be placed, such that there is a smooth base.
- Dig a toe trench for the keyway (if required) below where the riprap will be placed.
- Place 10-15 cm (4-6 in or 5-8 stem) bundles on the slope, with the butt ends placed at least 30 cm (1 ft) in the low water table. This will probably involve placing the poles in the toe trench before the rock is placed, if standard riprap rock is being used. Digging shallow trenches for the willows prior to placing them on the slope will decrease damage to the cuttings from the rocks, and may increase rooting success because more of the cuttings will be in contact with soil.
- The bundles should be placed every 1.8 m (6 ft) along the bank, and be pointed straight up the slope. Once the bundles are in position, place the rock on top of it to the top of the slope. The bundles should extend .3 m (1 ft) above the top of the rock. If the bundles are not sufficiently long, they will probably show decreased sprouting success, and therefore, a different technique should be chosen.

Vegetated Riprap with Bent Poles

- Grade back the slope where the riprap will be placed, such that there is a smooth base.
- Dig a toe trench for the keyway (if required) below where the riprap will be placed.
- If filter fabric is being used, lay the fabric down on the slope, all the way into the toe trench, and cut holes in the fabric about 0.6-0.9 m (2-3 ft) above the mean low water level. Slip the butt ends of the willow poles through the fabric and slide them down until the bases are at least 15 cm (6 in) into the perennial water table, or at the bottom of the toe trench, whichever is deepest (Hoag, 2002).
- If using filter gravel, lay it down on the slope, and place a layer of willow poles on top of the gravel, with the bases of the cuttings at least 15 cm (6 in) into the perennial water table, or at the bottom of the toe trench, whichever is deepest.
- Place the largest rocks in the toe trench. Ensure that they lock together tightly, as they are the foundation for the structure.
- Place the next layer of boulders such that it tapers back slightly toward the streambank.
- Bend several willow poles up, such that they are perpendicular to the slope, and tight against the first layer of rocks. Now place the next layer of rocks behind these poles. Placement will require an excavator with a thumb, as someone will have to hold the poles while the rocks are placed. As the poles are released, they should be trimmed to 30 cm (1 ft) above the riprap.
- This last step should be repeated until all the poles have been pulled up, and the entire slope has been covered.





Photo series showing installation of Vegetated Riprap with Bent Poles.

Vegetated Riprap with Brushlayering and Pole Planting

There are two methods of constructing brushlayered riprap; one involves building up a slope, and the other works with a pre-graded slope – neither method can be used with filter fabric.

Method 1

- Lay the bank slope back to somewhat less than the desired finished slope.
- Dig a toe trench, if needed, and lay the key rocks into the trench. Pack soil behind these rocks, with filter gravel in between the soil and rocks. Continue installing riprap 0.9-1.2 m (3-4 ft) up the bank (C. Hoag, personal communication, 2002).
- Slope the soil back into the bank at a 45° angle, such that the bottom of the soil slope is in the vadose zone. Place a layer of willow cuttings on top of the soil, with the butt ends extending into the vadose zone, and the tips of the branches sticking out 30-60 cm (1-2 ft).
- Place the next layer of stones on top of the initial rocks, but graded slightly back, and repeat the soil and brush layering process. When finished, trim the ends of the willow branches back to 30 cm (1 ft). Do not cut shorter than 30

cm (1 ft), as the plant will have difficulty sprouting.



Photo series courtesy CMRCD

Method 2

- Lay the bank slope back to the desired finished grade, and dig a toe trench if self-launching stone is not being used.
- Place the largest rocks in the key-way, and fill in behind with filter gravel and soil. Continue installing riprap 0.9-1.2 m (3-4 ft) up the bank (C. Hoag, personal communication, 2002).
- Place the bucket of an excavator just above the layer of rocks at a 45° angle. Pull the bucket down, still at a 45° angle, until the water table is reached, or the stream is dry, to the elevation at the bottom of the key trench. Pull up and back on the bucket; this will provide a slot in the bank into which willow poles can be placed (C. Hoag, personal communication, 2002).
- Throw in some willow poles (about 18 poles per linear m (6 poles per linear ft)), ensuring that the butt ends are at the bottom of the trench.
- Release the scoop of earth, and allow it to fall back in place on the slope. Then place the next layer of rock on top of the branches, flush with the slope. If self-filtering stone is not being used, filter gravel should be placed behind the rocks. Repeat the process, beginning again with pulling back a scoop of soil. Continue this process to the top of the slope, or if preferred, use joint-planted riprap on the upper slope, where it is difficult to reach the perennial water table with the excavator bucket.
- When finished, trim the ends of the branches back such that only 30 cm (1 ft) extends beyond the revetment (C. Hoag, personal communication, 2002).

14. COST

Installation of Vegetated Riprap will require about 2.5-6 man hours/m² (2-5 work hours/yd²). The cost of rock will vary depending on availability in the local area, but typically runs between \$22 to \$67 per metric ton (\$20 to \$60 per ton), delivered.

15. MAINTENANCE / MONITORING

Riprap should be visually inspected following any 1-year return interval or greater flow, with focus on potential weak points, such as transitions between undisturbed and treated areas. Soil above and behind riprap may show collapse or sinking, or loss of rock may be observed. Inspect riprap during low flows annually, to ensure continued stability of the toe of the structure. Treat bank or replace rock as necessary.

Also note any channel or habitat impacts that result from riprap installation and treat as needed.

16. COMMON REASONS / CIRCUMSTANCES FOR FAILURE

Flanking, overtopping or undermining of the revetment due to improperly installed or insufficient keyways is one of the biggest reasons for failure of riprap. Improperly designed or installed filter material can also cause undermining and failure of the installation. Undersized stones can be carried away by strong currents, and sections of the revetment may settle due to poorly consolidated substrate. Vegetation may require irrigation if planted in a nondormant state, or in extremely droughty soils. Also, vegetation may be limited by excess soil moisture (Pezeshki et al., 1998).

17. CASE STUDIES AND EXAMPLES

[San Vacinte Creek](#)

Flood flows from large storms in the winter of 1996-1997 resulted in erosion of a streambank on San Vacinte Creek, threatened three residential structures located on the high right-descending bank, and undermined an existing section of rock-filled gabion baskets protecting a commercial establishment located at the lower project reach. In 1998-99, vegetated riprap protection was installed along the project reach. In 2001, Vane and Rootwad Revetment structures were designed and installed to redirect flows away from and armor the toe of the riprap revetment.

[Branciforte Creek](#)

High flows during large storms events resulted in erosion of a streambank located on the downstream end of a low radius bend with highly erodible soil. The erosion threatened a residential structure located on the high right-descending bank. Between January and March of 2000, vegetated riprap and vegetated gabions were installed to reduce erosion. In June of 2000, vegetated gabions and brush layering with soil wrap were installed above the previous installation to stabilize the bank and encourage revegetation.

[Cedar Creek](#)

Scour was occurring on an outer bend of Cedar Creek in Northern California, which was causing serious erosion that had the potential to impact Highway 299. Riprap was used to armor the bank, and 9 bendway weirs were used to redirect flow away from the sensitive bank. Live stakes were installed at the toe, and willow posts were planted into and around all structures.

[Old 99 Creek](#)

Two old homesites and a large concrete culvert were obstructing Old 99 creek and had accumulated an estimated 5,000 yd³ of sediment in the creek bottom. This project removed the homesites, culvert, and sediment down to the historic creek bottom, and stabilized the restored channel with a series of 4 rock cross vanes and liberal willow post planting. A second component of this project was the removal of 2 undersized metal culverts and replacement with 3 larger concrete culverts. The upstream bank of the creek was treated with vegetated riprap, as it had been experiencing severe erosion due to scour during high flows.

Please visit the [Photo Gallery](#) for more pictures.

18. RESEARCH OPPORTUNITIES

Investigate the performance of this technique under conditions where banks are subjected to scour forces, bank overriding, or plucking action by ice. Does the presence/use of vegetation play a useful role? How does the vegetation or vegetative component respond to ice damage? What appears to enhance, or conversely, detract from the ability of

vegetation to perform well under icing conditions?

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