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Clark Fork River Operable Unit

of the Milltown Reservoir/Clark Fork River Superfund Site

Record of Decision

Appendix B:

Clark Fork River OU Streambank Stabilization Design Consideration and Examples

U.S. Environmental Protection Agency
Region 8

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April 2004

APPENDIX B

Clark Fork River OU Streambank Stabilization Design Consideration and Examples

Flood Hydrology on the Upper Clark Fork River

Because of the short periods of record for Clark Fork River gage stations within Reach A, a procedure to correlate the data with downstream stations having longer periods of record was conducted by R2 Resource Consultants (2000) to refine estimates of flood flows for various return periods. Two different calculations of peak flows at the Deer Lodge gage station (#12324200) are presented in Exhibit B-1 for several return flow periods. One calculation is based solely on the 21 years of actual gage data at the Deer Lodge station. The other calculation is correlated with a downstream gage having a longer period of record, which is used to extend the effective period of record at Deer Lodge to 48.4 years.

Bankfull flow of the Clark Fork River at Deer Lodge has been calculated to be about 1,900 cfs (Griffin and Smith 2001). At this stage, the flow begins to spill out of the channel and disperse onto the floodplain. When a river floodplain is broad relative to its channel width, as is the case for the upper Clark Fork, a flow stage above bankfull produces a large increase in overbank discharge. However, this occurs with a very small increase within the channel (Smith and Griffin 2002) because the increased flow is distributed over the floodplain at a shallow depth. Since both shear stress and velocity are functions of flow depth, these critical factors of erosion potential increase very slowly as total discharge increases beyond bankfull stage.

Referring to Exhibit B-1, a 25-year flood at 2,830 cfs is about 900 cfs above bankfull discharge. Throughout Reach A, the Clark Fork River has access to a floodplain in excess of one channel width wide on at least one side of the channel. Only in the town of Deer Lodge do high banks on both sides of the river confine the flows above bankfull stage causing an increase in flow depth instead of dispersing over the floodplain.

EXHIBIT B-1
Annual Peak Flow Calculations for the Clark Fork River at Deer Lodge USGS Gage No. 12324200

Return Period	Peak Flow (cfs) 21 Year Record	Peak Flow (cfs) 48.4 Year Record (Extrapolated)
2-year flood	987	1,090
5-year flood	1,610	1,750
10-year flood	2,050	2,220
20-year flood	2,490	2,680
25-year flood	2,630	2,830
50-year fllod	3,080	3,330
100-year flood	3,530	3,770

Streambank Stabilization Considerations

Designers of streambank stabilization projects must ensure that the materials placed within the channel or on the streambanks will remain stable over the full range of conditions expected during the design life of the project. Unfortunately, techniques to characterize stability thresholds are limited. Empirical data for shear stress or stream power are generally lacking, but the existing body of information is summarized here. The presence of dense, woody vegetation on streambanks can decrease erosion substantially by reducing the shear stress along the streambanks, and by increasing the cohesion of the soil comprising the streambanks (Griffin and Smith 2001).

The stability of a stream refers to how it accommodates itself to the inflowing water and sediment load. Erosion occurs when the hydraulic forces in the flow exceed the resisting forces of the channel boundary. The two traditional approaches for characterizing stream flow erosion potential use maximum permissible velocity or critical shear stress. Flow velocity can be measured directly, but shear stress cannot; however, shear stress is a better measure of the fluid force on the channel boundary than is velocity. Moreover, conventional guidelines, including ASTM standards, rely upon the shear stress as a means of assessing the stability of erosion control materials.

Vegetation has a profound effect on the stability of both cohesive and non-cohesive soils. It serves as an effective buffer between the water and the underlying soil. It increases the effective roughness height of the boundary, thereby increasing flow resistance and displacing the flow velocity upwards away from the soil. This reduces drag and lift acting on the soil surface. Since boundary shear stress is proportional to the square of the near-streambank velocity, a reduction in this velocity produces a much greater reduction in the forces causing erosion.

Vegetation armors the soil surface, but the roots and rhizomes of plants also bind the soil and introduce extra cohesion beyond any intrinsic cohesion of the streambank material. The presence of vegetation does not render underlying soils immune from erosion, but the threshold for erosion of a vegetated bank is usually the point of breakage or uprooting of the plants rather than the threshold for movement of the soil particles. Vegetation failure usually occurs at much greater flow intensity than does soil erosion.

The stability of a waterway or the suitability of various channel linings can be determined by first calculating actual mean velocity and shear stress. These values can then be compared with allowable velocity and shear stress for a particular treatment application.

Mechanics of Stabilizing Streambanks

Treatments are designed for streambanks where engineered safety needs to be combined with ecological function and aesthetics. This means they incorporate live, source-identified, site-adapted, vegetation with various applications of structural materials to protect the streambank from the erosive forces of the river water. The material is flexible (i.e. forgiving of grading mistakes), yet strong and easy to use. These materials are typically used in strong currents, high-energy sites, on steep slopes as erosion control material, and revegetation units for difficult sites where energy conditions require an instant solution of strength and stability and simultaneous re-establishment of vegetation. Another prime criteria for inclusion in this approach is that the treatments all minimize disturbance to the aquatic and the terrestrial riparian system during installation.

Coconut fiber coir blankets, mats, and logs that can be pre-vegetated with native plants are widely accepted and used as appropriate materials to protect erodible streambanks. However, for protecting streambanks that are exposed to the most severe erosive forces, a heavier engineering approach may be required. In the United States, since the advent of heavy machinery for moving earth and large rock, the use of large rock has become the most frequently applied solution in these placations. However, there is a cost effective, functionally effective, and aesthetically pleasing alternative that uses smaller rock (4-to-6 inch) compatible to, and readily available in, most river systems. This material is used throughout Europe to stabilize rivers. Rock roll and chambered rock mattress are products consisting of heavy duty polypropylene (environmentally inert) net casings that are filled at the site with suitably sized rock native to the local area and placed at the toe of the most vulnerable streambanks. Heavy equipment is required for installation.

Typical applications in Europe of the chambered rock mattress are on steep embankments with high erosive forces where engineered safety has to be combined with ecological function and aesthetics. Typical uses include:

- Toe protection
- Steep bank slopes (1:1.5)
- Channel liners and bridge aprons
- Submerged dams and shelves
- Reservoir inlet and discharge channels
- Filling-in of scour holes
- Jetties and guide dams
- Breakwaters
- Drainage layers

A sediment filter screen within the net casing of the rock roll and chambered rock mattress may be included that will allow the enclosed rock to collect sediment and become integrated into the natural streambank as rooting medium for vegetation, while blocking sediment from entering the stream. A great advantage of this method of protecting the streambank toe is the reduced need to disturb either the streambank or the channel bottom. These net casings containing smaller rock do not require digging of keyways and will conform to subsurface contours.

In moderate shear stresses/water velocities, rock rolls are another treatment, and they act as small, flexible, and permanent gabions. In turbulent flows, rock rolls are used to provide a solid foundation on top of which pre-vegetation coir rolls can be installed. The roots of plants then quickly grow into the voids of the rock rolls giving long term erosion control and bank support. Rock rolls that are installed below coir units can also be used to support a filter fabric or biodegrading matting. This system retains the fines in the streambank while the roots of the plants from the pre-vegetated coir units establish themselves into the streambank and through the woven geotextile into the suitable fill.

Traditional Approach

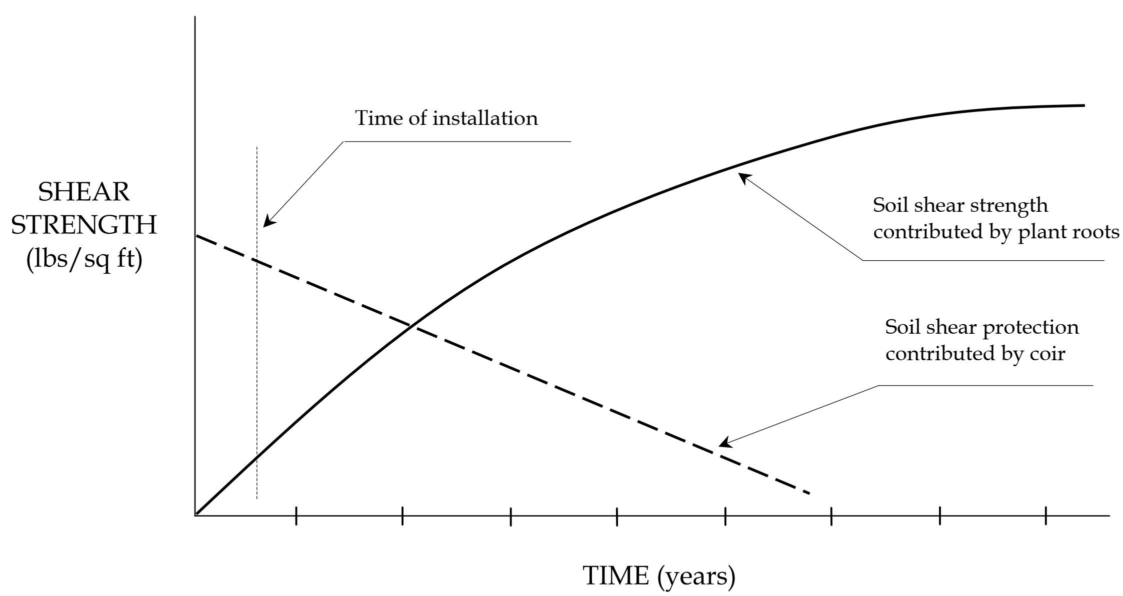
Traditional methods use a variety of methods for stabilizing various conditions of channel shear stress and flow velocity. Three typical levels of susceptibility to erosion and treatment types are:

1. Low to moderate (less than 3 to 4 feet per second velocity and less than 4 pounds per square feet shear stress), with treatment by revegetation
2. Moderate to high (less than 8 feet per second velocity and less than 6 pounds per square feet shear stress), with treatment by biotechnical methods (coir fabric, large rock toe protection, and revegetation)
3. High (exceeds 8 feet/sec velocity and exceeds 6 pounds per square feet shear stress), with hard structural treatment (rip-rap, with in-stream flow deflectors in some cases)

Bioengineering Approach

Commonly available bioengineered materials offer inherent resistance to shear stress on the order of 3 to 5 pounds per square foot. Several companies produce these materials in the form of logs in a variety of diameters for application along lines of high stress, and in mats for use on wider surfaces. These materials are available in several forms designed for particular applications in stabilizing disturbed sites with challenging potential for erosion. However, although these bioengineered materials (typically made of coir fiber from coconut husks) are very strong, they do biologically degrade over time, and are intended to supply stabilizing enforcement during the period necessary for live vegetation to become established and take over the mechanical soil stabilization duties (Exhibit B-2).

EXHIBIT B-2
Idealized relationship to show how over time the plant roots assume the entire role of reinforcing the soil strength to resist shear stress, as the coir biodegrades. Note that the actual strength is the sum of the two components, plus that of the soil's own cohesive strength.



Modern techniques have now been developed to grow the plants in the coir material in advance of application on site. In this way, the inherent strength of the coir is augmented from initial installation beyond the 3 to 5 pounds per square foot by whatever additional strength is also provided by the integrated roots of the live plants. These pre-vegetated coir products typically have the plants growing in the material for one growing season before installation on a project, so that the root systems of the plants are well developed and already providing substantial fiber strength and biomass to the coir product.

Unvegetated soil is generally strong in compression, but weak in tension. The fibrous roots of vegetation have the opposite characteristics; therefore, a composite of a soil permeated by plant roots has enhanced strength (Simon and Collison 2001). The amount by which plant roots augment soil strength varies immensely by species. According to Hoitsma and Payson (1998) vegetation resistance to shear stress is reported to vary from 0.35 to 8.50 pounds per square feet. Simon and Collison (2001), found that, even with the negative surcharge of the weight of trees, the net effect of adding riparian species to unvegetated banks was to double the effective strength when compared to unvegetated soil during a dry year (in Mississippi), using several species of riparian trees and grasses commonly used in revegetation projects in that region.

Goldsmith (1998) reports laboratory tests of strain resistance to shear stresses on blocks of riparian soil (medium sand texture) containing various kinds of plant root structures. These tests found that sedges increased resistance of the soil block to failure by a factor of 18.5 over a block of soil with no vegetation. Similar tests on a block with a single willow stem (0.6 inch diameter) and its associated sparse roots showed an increased resistance to failure by a factor of 3. A listing of ten studies measuring increases in soil cohesion due to the addition of roots of a variety of plant species shows universal increase that ranges from a factor of 2 to a factor of 17.5 (average increase = 5.7 times) (Coppin and Richards 1990). While we are less concerned with the load bearing strength of soils in the context of streambank stabilization and resistance to erosion, Goldsmith's comparison does reveal the magnitude of relative gains in soil strength contributed by the addition of plant roots. The following shear load to deform in pounds per square foot, according to Goldsmith, is as follows:

- Bare Soil (No Plant Roots): 64
- Soil with Sedge Roots: 1,184
- Soil with Willow Roots: 191

While every application is unique and all plant species differ in pertinent characteristics, we can be assured that integrating live plant roots into a coir product will significantly increase its inherent resistance to shear stresses. The intent is to transfer shear stress on the soil to tensile resistance of plant roots as a function of the interface friction along the root surfaces. This process can be greatly augmented and hastened by reinforcing a high-strength growth medium that comes with its own inherent resistance to shear stress. The tensile strength of plant roots also varies among species. Species of the genera *Salix* (willow), *Betula* (birch), and *Alnus* (alder) all have roots with tensile strengths in the range of 24.17 pounds per square feet to 27.92 pounds per square foot (Coppin and Richards 1990). Exhibit B-3 shows a comparison of properties of some of the different materials discussed above.

Pre-vegetated coir products described above can easily satisfy structural requirements for stabilizing streambanks in all but the most critical sites where public works infrastructure installations have to be protected in place by absolutely rigid structures. These pre-vegetated coir products provide even further gains in protection of banks through the added friction to flowing water from roughness because the plants grow from the coir. This added roughness slows the water velocity at the critical surface boundary layer, and steadily increases in effectiveness over time.

EXHIBIT B-3
Comparison of Streambank Material Properties

Boundary Material	Critical Boundary Shear Stress (lb/ft^2)	Critical Water Velocity (ft/sec)	Reference
Bare Soils			
Sandy Loam	0.03 – 0.04	1.75	(Chang 1988)
Alluvial Silt	0.045 – 0.05	2	(Chang 1988)
Mixed Silt to Cobble	0.43	4	(Chang 1988)
Rock			
1-inch Gravel	0.33	2.5 – 5	(Chang 1988)
2-inch Gravel	0.67	3 – 6	(Chang 1988)
6-inch Gravel	2.0	4 – 7.5	(Chang 1988)
Large Rock (Rip-Rap) (D50 = 2 feet)	10.1	14 – 18	(Kouwen, Li, Simons 1980)
Gabion	10	14 – 19	(Goff 1999)
Rock Roll (16 – 20 in. diameter)	12 (estimate)	At Least 16	
Chamber Rock Mattress (1 feet thick by 5 feet wide)	15 (estimate)	At Least 16	
Vegetated Soil			
Long, Native Grasses	1.2 – 1.7	4 – 6	(Fischenich 2001)
Hardwood Trees	0.45 – 2.5	Unknown	(Fischenich 2001)
Bioengineering			
Coir Roll-Sod (Unvegetated)	5	15	(Santha 2003)
Coir Roll-Sod (Vegetated)	4 – 8	9.5	(Gray and Sotir 1996)
Coir Roll-Sod (Pre-vegetated)[a]	12+	At Least 15	(Di Pietro and Brunet 2002)
Coir Fiber Roll (Un-vegetated)	3 – 5	8 – 16	(Fischenich 2001, Santha 2003)
Coir Fiber Roll (Pre-vegetated)[a]	12+	At Least 16	(Di Pietro and Brunet 2002)

[a] Critical shear stress and water velocity are based upon values at installation. After installation, the roots of the plants grow into the streambank and the values increase greatly.

Anchoring the Critical Streambank Toe—Traditional methods typically offer a design utilizing large rock to anchor the streambank toe. The toe of the streambank slope is where shear stress is greatest against the streambank, and where streambank failure is most likely to happen. Angular rock is typically required for such applications to achieve stability. Most sources of such material are distant and expensive. A simpler solution utilizes smaller rounded rock, readily available within the floodplain, in rock rolls or rock mattresses. These are tubes of strong netting in various configurations that are filled with this smaller rock on site and laid in place to protect the streambank toe. The netting is typically made of an environmentally inert material that holds the rock in place 10 to 20 years, or until the banks are well protected by natural vegetation. Added benefits are that the rock used in the rock rolls is locally obtained in the valley and is round. This means that the rock is native to the floodplain and the round rock is similar to the rock in the streambed and that it will provide interstitial spaces for macroinvertebrate habitat, which are an indicator of water quality and overall health. Large, angular rip-rap does not provide the same type and amount of such spaces.

Matching Streambank Stabilization Techniques and Materials to Site-Specific Criteria

The following paragraphs offer a general procedure for matching streambank stabilization techniques and materials to specific site applications in terms of actual erosion potential (Fischenich 2001).

Step 1: Estimate Mean Hydraulic Conditions

Flow of water in a channel is governed by the discharge, hydraulic gradient, channel geometry, and roughness coefficient. This functional relationship may be evaluated using normal depth computations that take into account principles of conservation of linear momentum, which take into account variations in momentum slope directly related to shear stress. Several models are available to aid in assessing hydraulic conditions. Notable examples include HEC-2, HEC-RAS, and WSP2. Channel cross sections, slopes, and Manning's coefficients should be determined based upon surveyed data and observed or predicted channel boundary conditions. Output from the model should be used to compute main channel velocity and shear stress at each cross section.

Step 2: Estimate Local/Instantaneous Flow Conditions

The computed values for velocity and shear stress may be adjusted to account for local variability and instantaneous values higher than mean. A number of procedures exist for this purpose. Most commonly applied are empirical methods based upon channel form and irregularity. Local maximum shear stress can be assumed from the following simple equations (Fischenich 2001):

$$\lambda_{max} = 1.5t \text{ (for straight channels)}$$
$$\lambda_{max} = 2.65(R_c/W)^{-0.5} \text{ (for sinuous channels)}$$

Where λ is the computed value of actual shear stress at a cross section, R_c is the radius of curvature, and W is the top width of the channel. These equations adjust for the spatial distribution of shear stress; however, temporal maximums in turbulent flows can be 10 to 20 percent higher. A further adjustment is needed to account for instantaneous maximums, and a factor of 1.15 is usually applied (Fischenich 2001).

Step 3: Determine Existing Stability

Existing stability should be assessed by comparing estimates of local and instantaneous shear and velocity to values for the materials available for use. Both the underlying soil and the soil/vegetation condition should be assessed. If the existing conditions are deemed stable and are in agreement with other project objectives, then no further action is required. Otherwise, proceed to Step 4.

Step 4: Select Channel Lining Material

If existing conditions are unstable, or if a different material is needed along the channel perimeter to meet project objectives, then the new material or stabilization measure should be selected by using the critical threshold values as a guideline. Only material with a threshold exceeding the predicted value plus safety factor should be selected.

Suggested Design Criteria for Clark Fork River Streambank Treatments

Exhibit B-4 shows the suggested maximum values of shear stress and flow velocity for the proposed streambank treatment designs for the Upper Clark Fork River.

EXHIBIT B-4
Allowable Maximum Values of Shear Stress and Flow Velocity for Bioengineered Streambank Treatment Designs

Treatment	Description	Maximum Allowable Shear Stress (lb/ft^2)	Maximum Allowable Flow Velocity (ft/sec)
Treatment 2	Pre-vegetated Coir	8[a]	9.5[a]
Treatment 3	Pre-vegetated Coir and Rock Roll	10[b]	15[b]
Treatment 4	Pre-vegetated Coir and Rock Mattress	12[b]	16[b]

[a] from Gray and Sotir (1996)
[b] from Di Pietro and Brunet (2002)

Examples of Streambank Treatments for Various Conditions

Once the data for various streambank reaches is completed and interpreted and the appropriate lengths of banks by classification is determined, appropriate streambank stabilization designs, depending on classification, can then can be determined. Components of the following designs includes a bio-engineering component for physically stabilizing the streambank and streambank toe if appropriate. Also included are revegetation plans for the riparian corridor that further serve to stabilize and protect the installed streambank erosion protection component but further serve to protect the riparian corridor from floodplain flow erosion as well. Over time, as these differing sizes of woody vegetation mature, both streambank and floodplain erosion protection will increase.

The following treatment designs are those designs developed as examples for the Upper Clark Fork River. Final decision on the actual design specifications will be made in the remedial design phase. As the streambank work progresses, site-specific designs or other designs will be necessary. The treatments are ordered from low shear stresses and flow velocities to high shear stresses and high velocities. The diagrams shown throughout this discussion are not drawn to scale.

1. **No Treatment Necessary**—This applies to streambanks where there is adequate deep, binding woody vegetation already in place, and no additional work on the site is necessary.

2. **Treatment 1 (vegetation augmentation)**—Augment existing vegetation with additional small-containerized plants. May require scalping and weed barriers for better survival. Assumption is that in this treatment, the average canopy cover of deep, binding woody vegetation is 50 percent. Therefore, the treatment will be the planting of 10 containerized plants at a level of 10 plants per 10 feet or 1 plant per linear feet of streambank. The mixture would be as follows:

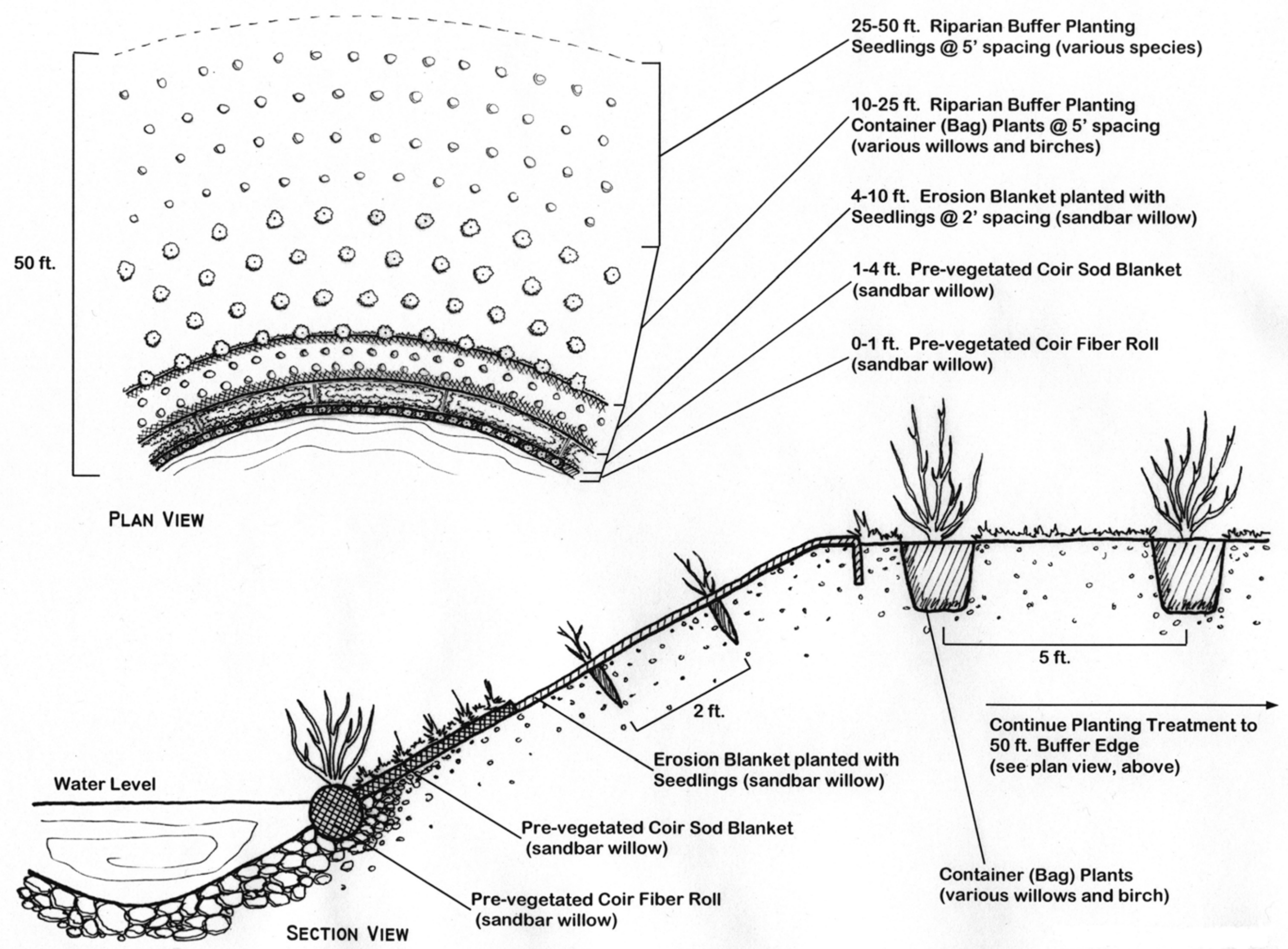
- 25 percent *Salix exigua* (sandbar willow) wet areas
- 25 percent *Betula occidentalis* (water birch) wet areas
- 50 percent equal mixture of *Salix lutea* (yellow willow), wet areas; *Salix boothii* (Booth willow), wet areas; *Salix bebbiana* (Bebb willow), wet areas; *Alnus incana* (mountain alder), wet areas; *Cornus stolonifera* (red-osier dogwood), wet areas; *Prunus virginiana* (common chokecherry), dry areas; and *Amelanchier alnifolia* (western serviceberry), dry areas.

3. **Treatment 2 (low shear stresses/flow velocities)**—Pre-vegetated coir roll-sod with a toe protection of pre-vegetated fiber-rolls (comprised of sandbar willow [*Salix exigua*]) is considered Treatment 2 (see Exhibit B-5). Because of the sandy/gravelly streambank material (relatively unconsolidated in many places), the species mix for the roll-sods will be exclusively *Salix exigua* (sandbar willow). In other words, it is too sandy (therefore too droughty) for sedges to take hold. They need to have more silt/clay in the soil profile. Within the nominal 50-foot zone, the following will apply:

   a. 1-to-25 foot zone
      i. Pre-vegetated coir fiber-roll for toe protection (*Salix exigua* [sandbar willow]).
      ii. 3 feet of pre-vegetated coir roll-sod planted with *Salix exigua* (sandbar willow).
      iii. 6 feet of coir woven blanket (23 oz./square yard) planted with two rows of 10T containerized *Salix exigua* (sandbar willow) on a 2-foot spacing.
      iv. Three rows of bag plants of *Salix exigua* (sandbar willow) and *Betula occidentalis* (water birch) at a ratio of 2:1 (sandbar willow:water birch). The three rows will be on 5-foot spacing with the first plant at 10 feet and the last plant at 20 feet from the edge of the stream. These plants will be augered into the floodplain so that the roots are in constant contact with capillary fringe throughout the growing season.
      v. One row of bag plants of an equal mixture of *Salix lutea* (yellow willow), *Salix bebbiana* (Bebb willow), and *Salix boothii* (Booth willow).

   b. 25 to 50 foot zone
      i. Four rows of 10T containerized shrubs at a 5 foot spacing. The plants include *Salix lutea* (yellow willow) wet areas; *Salix boothii* (Booth willow) wet areas; *Salix bebbiana* (Bebb willow) wet areas; *Alnus incana* (mountain alder) wet areas; *Cornus stolonifera* (red-osier dogwood) wet areas; *Prunus virginiana* (common chokecherry) dry areas; and *Amelanchier alnifolia* (western serviceberry) dry areas.

EXHIBIT B-5
Streambank Treatment 2—Low Shear Stresses/Flow



4. **Treatment 3 (moderate shear stresses/flow velocities)—**Pre-vegetated coir roll-sod with a toe protection of pre-vegetated fiber-rolls comprised of *Salix exigua* (sandbar willow) on top of rock roll is considered Treatment 3 (see Exhibit B-6). Also included is tipped over mature willow on a spacing of 15 feet along the streambank to deflect and dissipate the energy of the stream. The design for the zone behind the immediate streambank work is the same as Type 2 Treatment.

   Exhibit B-7 illustrates the typical installation for the rock roll and pre-vegetated coir fiber roll.

EXHIBIT B-6
Streambank Treatment 3—Moderate Shear Stresses/Flow

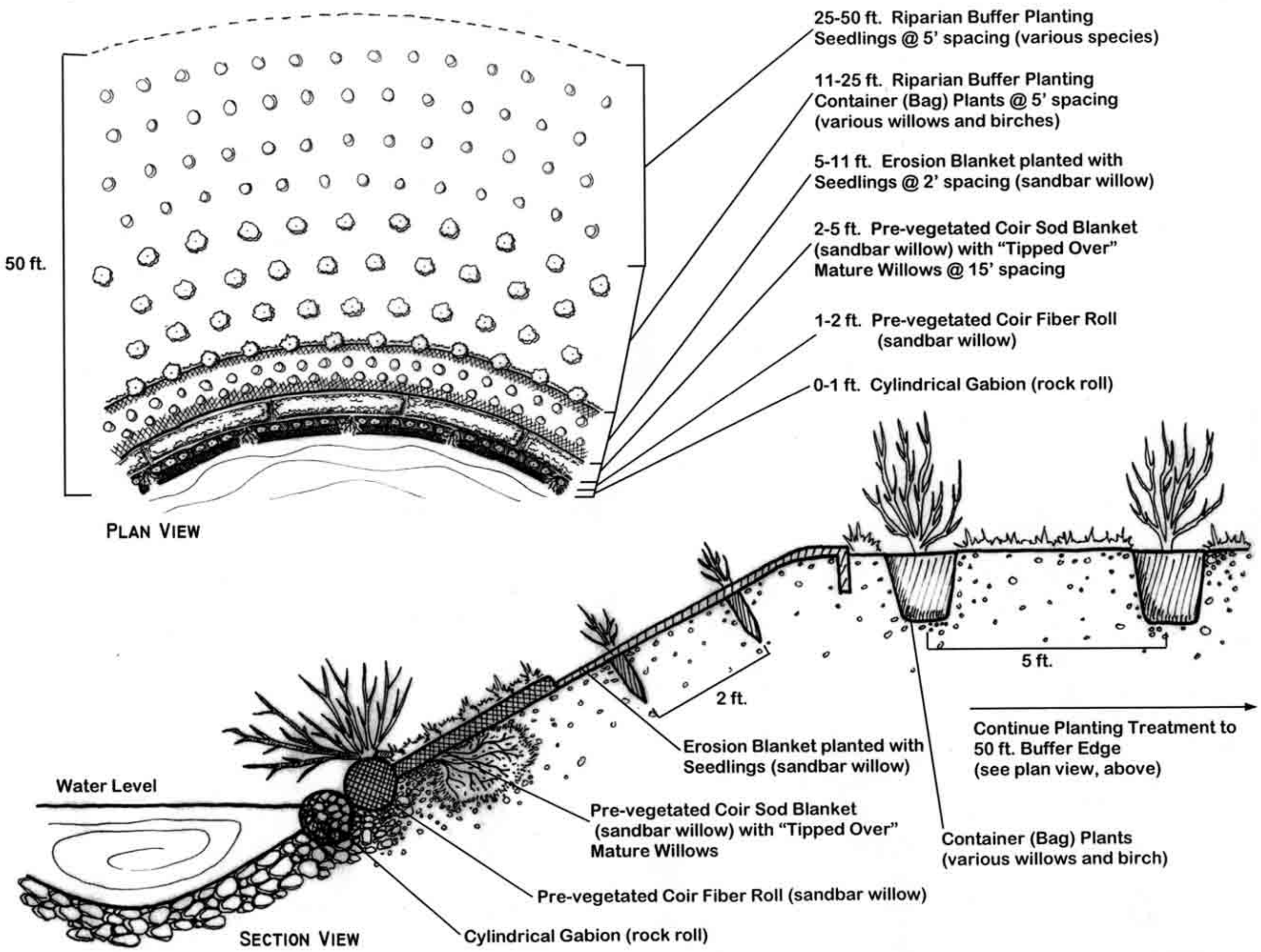
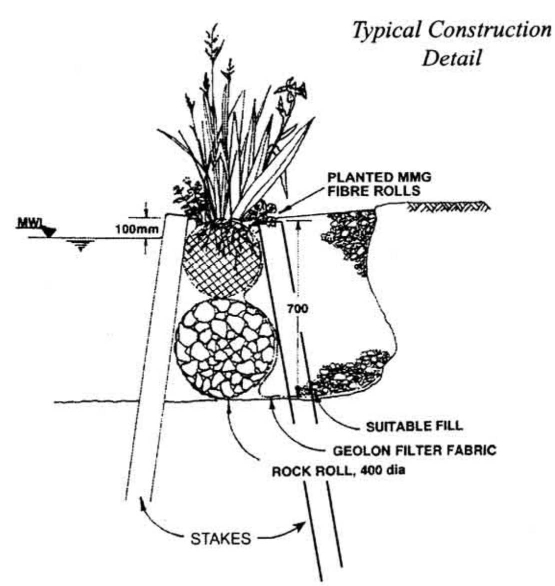
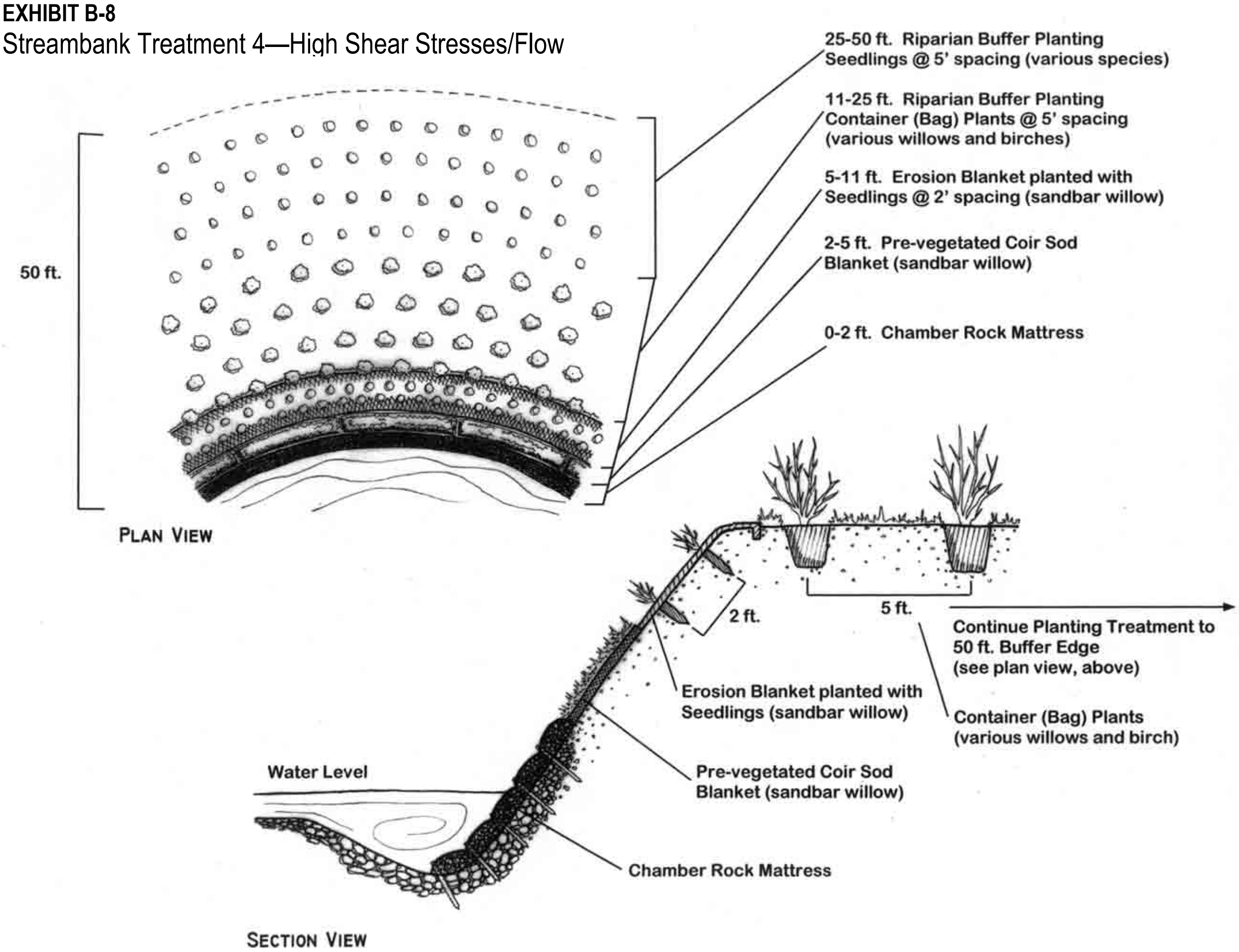


EXHIBIT B-7
Typical Construction Detail



5. **Treatment 4 (high shear stresses/flow velocities)**—Pre-vegetated coir roll-sod with a toe protection of rock mattress is considered Treatment 4 (see Exhibit B-8.) Also included is tipped over mature willow on a spacing of 15 feet along the streambank to deflect and dissipate the energy of the stream. The design for the zone behind the immediate streambank work is the same as Type 2 Treatment.

EXHIBIT B-8
Streambank Treatment 4—High Shear Stresses/Flow



Bio-Stabilization

As shown in the illustrations above, willow sprigs planted near the edge of the river and tipped-over willows (which deflect water flow away from the streambank) are to be the first structures to stabilize the banks of the river. Additional stabilization is achieved by planting "bagged" willows and mature willow transplants. These four types of bio-stabilization are implemented within the first 25 feet away from the river streambank. The second 25 feet away from the streambank is planted with additional bagged willows, and other woody vegetation including chokecherry, red dogwood, alder, serviceberry, water birch, and others. The intensity of woody plants is less for inside bends compared to outside bends of the river. Herbaceous communities are also to be established within this zone to provide riparian pastures for use by livestock and wildlife. This approach will provide herbaceous forage production for the landowner and maximum growth of woody vegetation to protect against erosion, soil loss, and floodplain deformation. A key component in establishing successful woody and herbaceous vegetation within the riparian corridor buffer will be supplemental irrigation for 2 to 3 years following implementation. This will provide optimum growth of these stabilizing plants, thereby reducing the time to attain streambank stability, as well as overall floodplain stability. In addition, supplemental irrigation will hasten establishment of grasses and forbs, and retard the invasion of unwanted plant species, specifically weeds.

Salix exigua (sandbar willow) is considered either an obligate wetland species or a facultative wetland species. Therefore, *Salix exigua* (sandbar willow) needs to be close to the water table to survive. If supplemental watering is not available, planting depth of the root-control bags can be adjusted to compensate. The planting depth should be deep enough so that the plant is in constant contact with the capillary fringe throughout the growing season. Planting *Salix exigua* (sandbar willow) at this depth will not affect the health of the plant. *Salix exigua* (sandbar willow) evolved in an environment where sediment deposition of up to 1 to 2 meters after a single high flow event (e.g., flood) can occur. When this happens, the plant develops new roots along the entire length of the buried stems. Therefore, augering the holes deeper can be used to compensate for supplemental watering concerns.

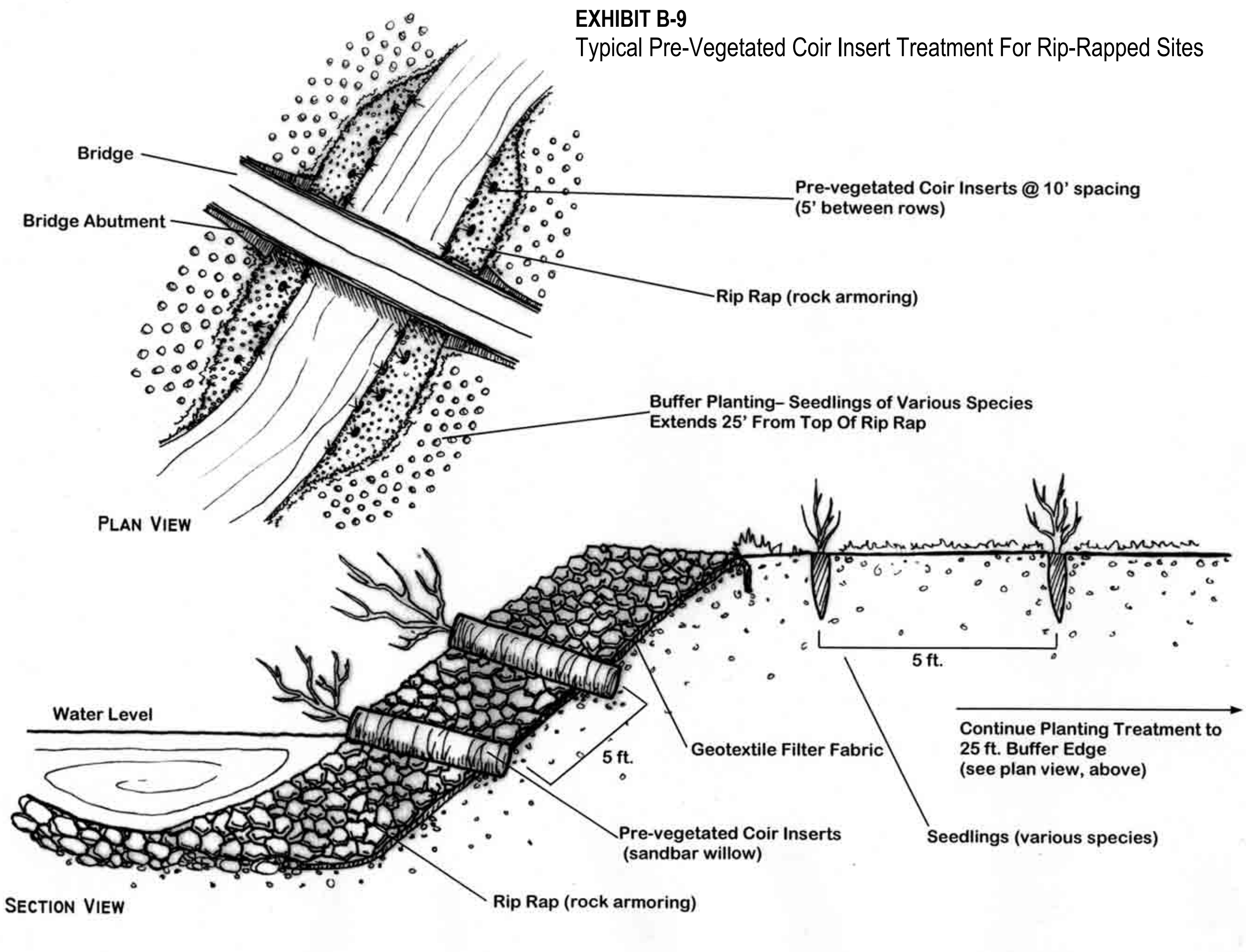
Additional Possible Streambank Treatments

The following examples are possible treatments for unique locations along the upper Clark Fork River. They have not been included in the cost analysis for the river.

1. **Modification of Existing Rip-Rap**—Existing rip-rap can be supplemented with pre-vegetated coir inserts (comprised of *Salix exigua* [sandbar willow]). Currently, rip-rap is associated with public infrastructure, such as bridges, irrigation diversion ditches, sewage lagoons, City of Deer Lodge, etc. The pre-vegetated coir inserts will be two rows, with the first row near the water level for the middle of the summer and another row 5 feet higher on the rock. The inserts will be spaced at 10 foot intervals. Behind the rip-rap, those areas outside an immediate transportation corridor right-of-way will include a buffer of 25 feet with four rows of 10T containerized shrubs at a 5 foot spacing. The plants include *Salix lutea* (yellow willow), wet areas; *Salix boothii* (Booth willow), wet areas; *Salix bebbiana* (Bebb willow), wet areas; *Alnus incana* (mountain alder), wet areas; *Cornus stolonifera* (red-osier dogwood), wet areas; *Prunus virginiana* (common chokecherry), dry areas; and *Amelanchier alnifolia* (western serviceberry) dry areas. See Exhibit B-9.

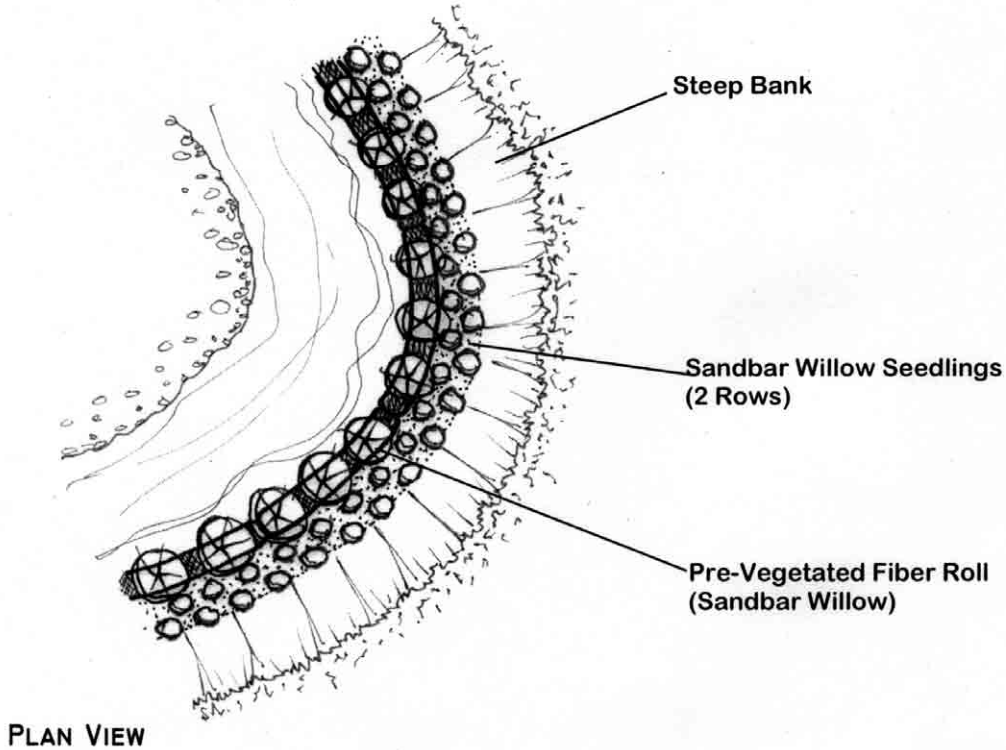
2. **In-stream Flow Deflectors or Low Rock Barbs**—See the Atlantic Richfield Company's Type 4 streambank stabilization option for a drawing of this type of structure (2002, *Feasibility Study*, Figure 5-12). (In the *Feasibility Study*, the Company does not include a cost estimate or a linear foot estimate.)

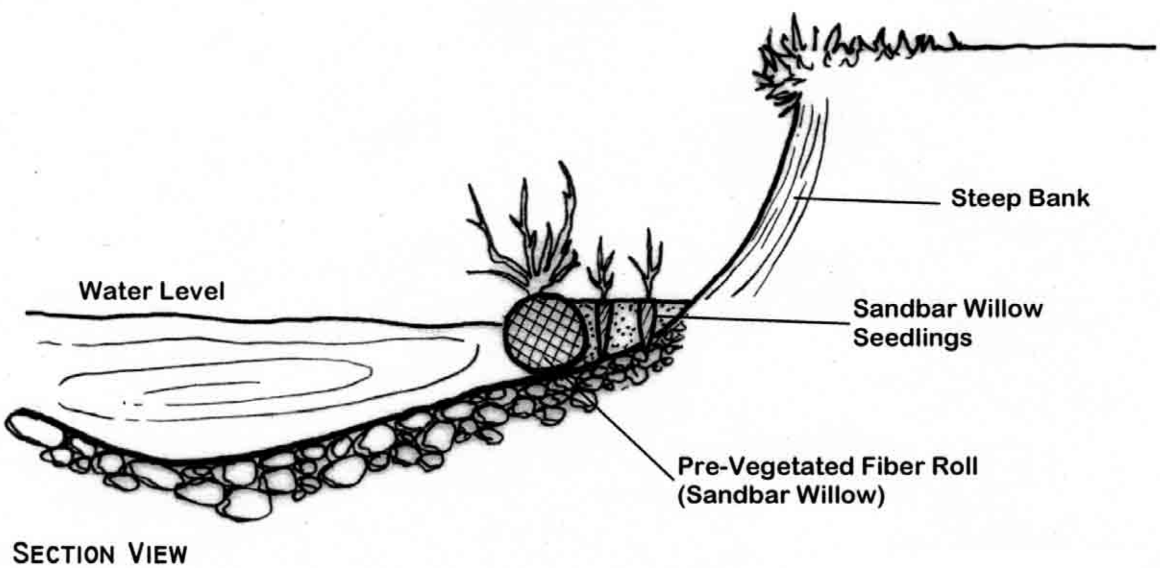
EXHIBIT B-9
Typical Pre-Vegetated Coir Insert Treatment For Rip-Rapped Sites



3. **Pre-vegetated Coir Fiber-rolls (comprised of *Salix exigua* [sandbar willow])**—Used along the base of high eroding banks. Immediately behind the fiber-rolls are two rows of small-containerized plants comprised of *Salix exigua* (sandbar willow). See Exhibit B-10.

EXHIBIT B-10
Typical Pre-Vegetated Coir Fiber Roll Treatment For Steep Banks





Sources

Atlantic Richfield Company. 2002. Feasibility Study Report. Milltown Reservoir Sediments NPL Site. Clark Fork River Operable Unit. ARCO Environmental Remediation Limited, Anaconda, Montana, USA. 1,580 p.

Chang, H. H. 1988. Fluvial processes in river engineering. John Wiley and Sons, New York, citing Fortier, S., and Scobey, F. C. (1926) Permissible canal velocities, Transactions of the ASCE, 89:940-984.

Coppin, N. J. and I. G. Richards. 1990. Use of vegetation in civil engineering. Construction Industry Research and Information Association (CIRIA). Butterworths, London, United Kingdom. 292 p.

Di Pietro, Paolo and Ghislain Brunet. 2002. Design considerations related to the performance of erosion control products combined with soil bioengineering techniques. Geotechnical Testing Journal, GTJODJ, Vol. 25, No. 2, June 2002. ASTM International. West Conshohocken, Pennsylvania, USA. pp. 142-147.

Fischenich, C. 2001. Stability thresholds for stream restoration materials. Technical Note: ERDC TN-EMRRP-SR-29. US Army Corps of Engineers Research and Development Center. Vicksburg, Mississippi, USA. 10p.

Goff, K. 1999. Designer linings. Erosion Control, Vol. 6, No. 5 (as cited by Fischenich 2001).

Goldsmith, Wendi. 1998. Soil reinforcement by river plants: progress results. *In:* Proceedings of the Wetland Engineering and River Restoration Conference 1998, American Society of Civil Engineers. Washington DC, USA. 7 p.

Gray, D. H. and R. B. Sotir. 1996. Biotechnical and soil bioengineering: a practical guide for erosion control. John Wiley and Sons, New York, New York, USA.

Griffin, E. R. and J. D. Smith. 2001. Analysis of vegetation controls on bank erosion rates, Clark Fork of the Columbia River, Deer Lodge Valley, Montana. WRIR 01-4115. USDI Geological Survey, Boulder, Colorado, USA. 8 p.

Hoitsma, T. R. and E. M. Payson. 1998. The use of vegetation in bioengineered streambanks: shear stress resistance of vegetal treatments. Wetland Engineering and River Restoration Conference 1998. American Society of Civil Engineers. Washington DC, USA.

Kouwen, N.; Li, R. M.; and D. B. Simons. 1980. "A stability criteria for vegetated waterways." Proceedings, International Symposium on urban storm runoff, as cited by Craig Fishcenich (2001).

Santha, Calista R. 2003. President ROLANKA International. Personal Communication (3/27/2003)

Simon, A. and A. J. C. Collison. 2001. Quantifying the mechanical and hydrologic effects of riparian vegetation on streambank stability. Earth Surface Processes and Landforms. Published online in Wiley InterScience (www.interscience.wiley.com) DOI: 10.1002/esp.325. 20 p.

Smith, J. D. and E. R. Griffin. 2002. Relation between geomorphic stability and the density of large shrubs on the flood plain of the Clark Fork of the Columbia River in the Deer Lodge Valley, Montana. WRIR 02-4070. USDI Geological Survey, Boulder, Colorado, USA. 25 p.