# APPENDIX G

# Expedient Measures for Mitigating Erosion along Rivers

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# Introduction

This appendix is intended to describe some low cost erosion protection alternatives for Alaskan communities located on the banks of rivers which experience erosion. Riprap and quarry stone revetments are the tried-and-true methods for stream bank protection, but they are costly to install and require significant planning to gather resources to produce a successful project. The methods described in this appendix are expedient measures that can be implemented by communities to mitigate the effects of erosion at a lower cost and on a faster time frame. These methods use locally available materials as much as possible and require a minimum amount of skilled labor and heavy machinery. While these methods are not as effective as riprap or quarry stone revetments, they can be constructed on a faster schedule buying a community time to gather resources to implement a more permanent solution.

Some of the methods presented in this appendix can be used in conjunction to save costs; for example, a spruce tree revetment can be used to protect a bank from the toe to the waterline while a brush mat is employed to cover the upper bank. For all of the biological erosion control structures (BECS), adding rock to the toe improves stability and longevity. Where rock cannot be obtained initially, it may be possible to add this once the BECS is in place. Generally speaking, though, if rock is to be used as part of a BECS project, it should be installed first if possible to avoid damage to the vegetation.

For all of the methods mentioned in this appendix, time needs to be given for planning and engineering activities to ensure that the scope and details of the work will produce the desired results. Even for a project with a short expected service life, planning and design are needed to ensure that effort is not wasted and adverse consequences are avoided.

The costs estimates presented for each respective method is for comparative purposes only and do not represent site-specific costs. Estimating the cost of a specific project should be made given full consideration of site conditions and contractor availability. No attempt was made to account for the mobilization of equipment to a site as this varies widely throughout the state depending on the site location. Due to the limitations of the cost data presented, the costs listed here should not be used as the basis for a construction estimate.

# 1 Definitions

Baseflow – Flow levels in a river

Biological Erosion Control Structure (BECS) – A structure using primarily biological components designed to mitigate erosion along a bank.

Bole – The trunk attached to a root wad which has been stripped of branches.

Filtering – A concept important to revetments. Filtering is a process of preventing in-situ soil from pumping through voids in a structure by providing a barrier tight enough to retain the material behind it. Filtering may be provided by a geo-textile or by successive layers of increasing particle size in rock revetments.

Geo-textile – A product used as a soil reinforcement agent and as a filter medium. It is made of synthetic fibers manufactured in a woven or loose nonwoven manner to form a blanket-like product.

Ordinary High Water (OHW) - The boundary between upland and riverbed. It is the point on the bank or shore up to which the presence and action of the water is so continuous as to leave a distinct mark either by erosion, destruction of terrestrial vegetation, or other easily recognized characteristics.

Revetment – A structure placed on a riverbank designed to protect the existing soil from hydraulic forces

Slope – A measure of the steepness of a bank or revetment shown as a ratio of horizontal increase to vertical increase. For example, a slope that rises 1 foot for every 2 feet in distance is a 2:1 slope.

Stream Forming Flow – the flow of the river at bank full conditions when water level is at the top of the banks but not in the flood plains.

Thalweg – The deepest point in the cross section of a river where the fastest currents flow.

Toe – The bottom portion of a sloping surface where it intersects a surface of shallower slope. On rivers, this is where the sloping river bank meets the riverbed.

# 2 Site Considerations

This section describes some of the factors that should be considered when planning and designing a project to protect any specific reach of a stream.

## 2.1 *River Morphology*

Rivers and streams are dynamic systems that respond to changes in flow and sediment. Usually, these changes alter the course of the stream or the shape of its banks. The current of a river typically flows fastest over the deepest portion of the channel called the thalweg. Most streams in Alaska are meandering streams that follow sinuous paths. At river bends, the thalweg is located along the outside bend called the cut bank. These faster currents are directed into the bank and tend to cause erosion. Along the inside bank, or point bar, the current is slowest. These slower currents tend to cause deposition. By these two processes, rivers tend to meander towards the outside banks of their bends. Over time, the channel of the river will shift laterally.

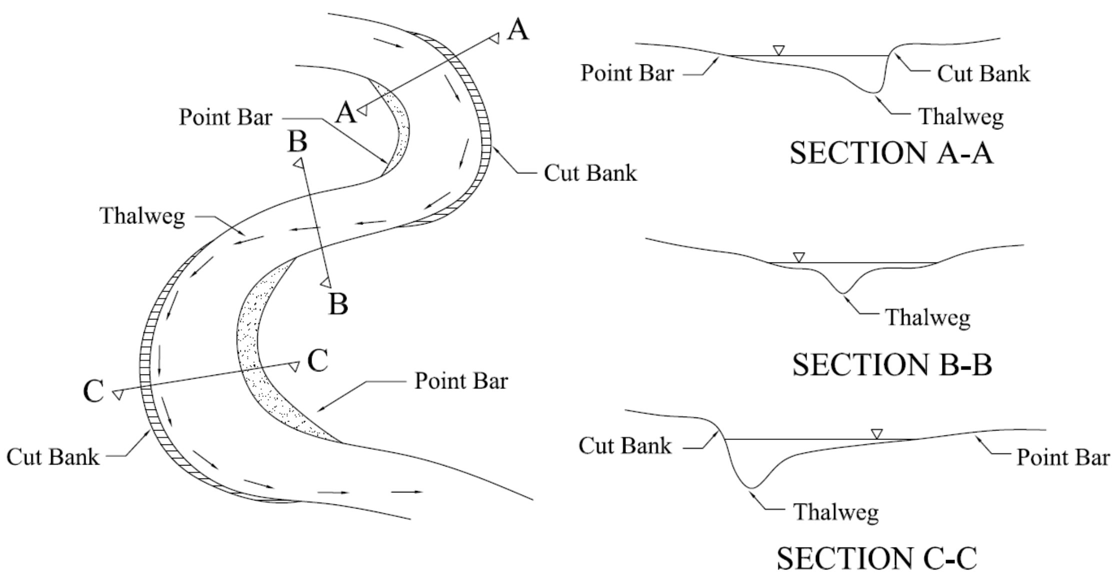


**Figure 2.1: Morphology of a meandering stream.**

Each stream and each project site along a stream is both dynamic and unique. Streams constantly change their alignment and channel dimensions to adjust to changes in flow and grade. Some channels develop bends and braids in response to a high sediment load while others may straighten in response to increased flow. A successful project needs to account for the likely configuration of the river throughout its design life. Rivers tend to continue to move in the same direction in the future as they are moving now. Project limits must take into account the likely movement of the river upstream and downstream to avoid being flanked or unraveled. In general, it is necessary to protect an entire bend of a river to produce stable results. If the downstream end of the extent of erosion is not protected, erosion will undermine the project and cause progressive failures from the downstream end to the upstream end in a process called unraveling. If the upstream end of the cut bank is not protected, the river will undermine the upstream end of the project causing it either to unravel as described above in the opposite direction or cause a more drastic failure if the project depends upon the strength of upstream elements.

## 2.2 *Upstream and Downstream Effects*

The act of placing material in the water of a river changes its behavior. Adding material can cause a channel constriction affecting water levels upstream of the project site. Protecting one stretch of bank with a hardened structure leads to faster currents along the bank boundary resulting in increased scour downstream of the project where no protection is given. Rates of erosion downstream of a project are generally increased, so care should be taken to ensure that the downstream extent of protection is located in a place where accelerated erosion will not pose a problem.

## 2.3 *Flow conditions*

Flow conditions on rivers are constantly changing. Seasonal changes due to precipitation and freezing can cause dramatic changes from virtually no flow in the channel due to freezing to flood stage events due to large rainstorms or warming events. While erosion can be a continuous process in streams, it will usually be most significant during high flow events. Flow velocity is greatest when a reach experiences stream forming flow, when the water level is at the top of the bank, but not in the floodplain. These high velocities cause the greatest rates of erosion. Beyond seasonal changes, long term trends can either increase or reduce the amount of water carried by a river. Rivers react to changes in flow by altering channel geometry to best accommodate the water. A channel experiencing increasing flow may become wider and straighter to allow it to carry the water to its terminus more quickly. Where flows are reduced, the channel may become braided as velocities decrease causing suspended material to settle out more quickly.

## 2.4 *Tidal Influence*

At the mouths of rivers, tidal variations influence the level of the river. Bank stabilization projects need to address the wetting and drying effects on the soils of the banks. This may be accounted for by assuming that soil is saturated throughout the tidal range. Also, the changing of the tide influences the current of the river. In low discharge systems, current can flow in both directions through a river reach. Currents at the site to be protected should be fully understood to minimize unintended erosion beyond its extents. Also, the presence of saltwater in the channel may prohibit the use of BECS. While some plant species tolerate a certain amount of salinity, many species commonly used in BECS require fresh water. A botanist should be consulted to determine what species can be used at any given site.

## 2.5 *Soil conditions*

Soil conditions at the site may preclude the use of some erosion control methods. Biological erosion control structures in particular are dependent upon the permeability and salinity of the soil and should be used only if site conditions will allow the plants to grow. As noted above, a botanist should be consulted before a decision is made to move forward with a BECS.

Slope stability needs to be examined to prevent global failure of the project. Slopes in soil are held up by the shear strength of the soil. This internal resistance must be able to resist the force of gravity on the soil itself and any weight imposed on the slope by the protection project. When the forces imposed on a slope exceed the shear strength of the soil, the slope fails and the soil re-distributes itself to a more stable configuration (Figure 3.2). When bank protection is installed on a river, the weight of the structure adds to the forces acting on the slope. Some structures also impede the flow of water, especially when filter fabric is used. This can be a problem as well because as the water content in soil increases, its strength decreases. Having a slope stability failure under a structure degrades its ability to protect the bank, sometimes destroying the structure outright.

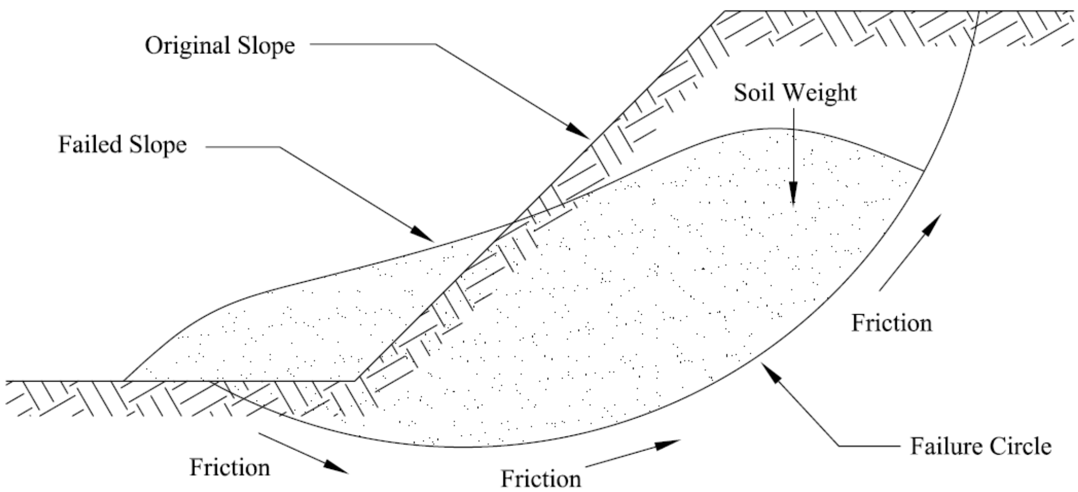


**Figure 2.2: Factors in slope stability.**

## 2.6 *Scour at the toe of the bank*

Most erosion problems along rivers are due to failure of the bank at the toe. Toe failure can cause a large loss in bank material in one event. A successful project will address toe erosion problems and have a toe sufficiently armored to withstand the forces eroding the toe of the bank. Lack of toe protection can result in slope stability issues as described above.

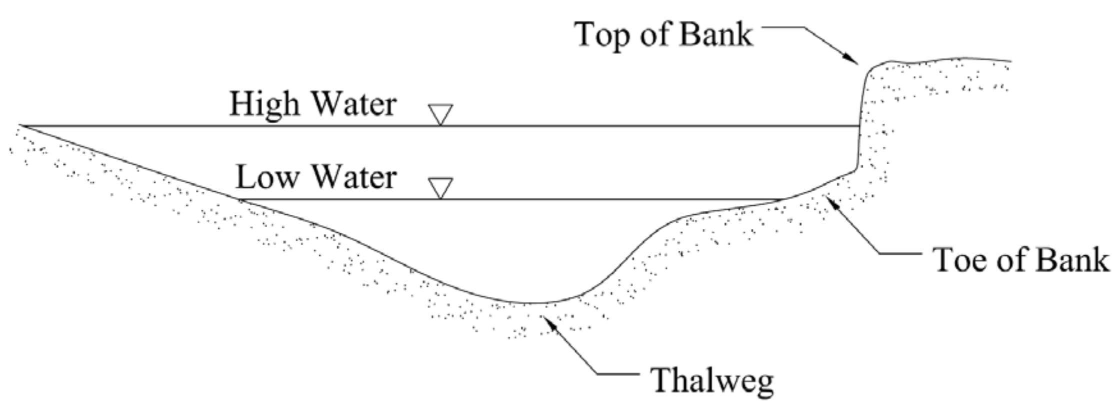


**Figure 2.3: Top and toe of a river bank**

## 2.7 *Filtering*

Filtering is an important consideration for any project in which bank materials are retained behind an engineered structure. This principle is most commonly seen in stone revetments. A structure which employs proper filtering will protect the bank material from erosion by preventing material loss from behind the structure. Without filtering, bank material can be lost through the voids between the protective elements of a structure. Filtering can be provided either by progressive gradations of rock or with filter fabric. In rock structures, the bank is covered with a layer of filter rock sized to retain the bank soil. The filter rock is covered with an intermediate sized rock designed to retain the filter rock. This is then covered with armor rock sized to resist the hydraulic forces of the site. This type of filtering drains well and has proven to be effective over years of use. Using filter fabric can retain bank materials under an armor layer, but has its drawbacks. Filter fabric forms a discrete boundary between the soil and the armoring. As a result, there is a plane of weakness between the armor and the bank which can sometimes cause armoring units to slide down the slope leaving sections of fabric covered bank exposed. Also, filter fabric can become plugged with small particles creating a barrier to drainage. If seepage through the bank is an issue, a buildup of water pressure behind the fabric may cause a blow out exposing a section of bank to the river.

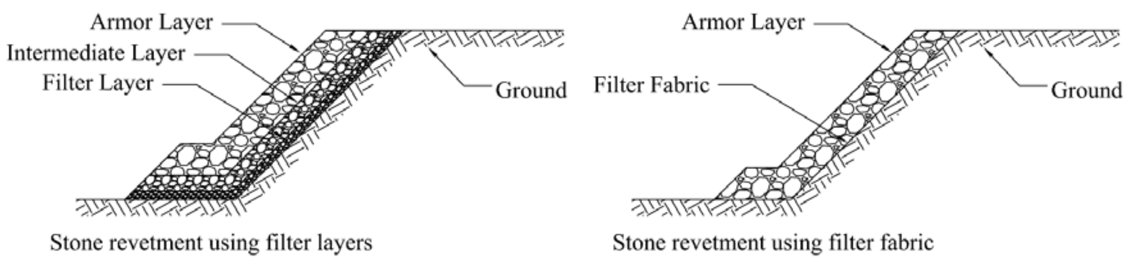


**Figure 2.4: Filtering techniques for stone revetments**

## 2.8 *Site Use*

Current and future uses of the eroding stream bank may prohibit the use of some kinds of erosion control. In general, when the eroding bank is needed for moorage or access to the stream, biological erosion control structures should not be used because they impede access to the river. Anchoring to or tying off on a bank stabilized by biological means may damage the structure and should be prohibited.

# 3 Biological Erosion Control Structures

Biological erosion control structures (BECS) refers to one of many streambank protection techniques that may be used by itself or in conjunction with other techniques. The methods described in this appendix are only some of the techniques that can be used. If a BECS project is being considered, consult “Streambank Revegetation and Protection” available from the Alaska Department of Fish and Game and attached to this appendix for more detailed descriptions of these methods. In general, biological structures are temporary in nature and need regular, in some cases annual maintenance to be effective over a long period of time. Most of these techniques are best suited to small streams with low velocities and may be impractical to implement on the community scale.

## 3.1 *Live Staking*

Where bank soils support willows, live stakes can be used to mitigate erosion by providing a living stand to trees along the bank. Live staking is a method of vegetating a bank by taking cuttings from willows in a dormant state and installing them into a bank where willows are currently not growing. Willows stabilize the upper portions of banks by reducing water velocity within the growth of trees and by providing a root structure that helps retain soil.

Live staking can be performed on stream banks which provide suitable habitat for willows. A good indicator of suitability would be the presence of native willows along the river. Some regions of the state do not support willows due to water, wind or temperature conditions. Where willows can grow, materials for live staking are usually nearby.

### 3.1.1 Cost

Streambank Revegetation and Protection (2005) reports a cost of $1.50 for willow cuttings. A live staking project on Cottonwood Creek placed stakes over about 2300 square feet in a six hour shift with a crew of ten. Using a spacing of 3 feet between stakes in a triangular arrangement, Davis-Bacon wages for Alaska, live staking costs approximately $1 per square foot to install. This cost does not include the cost to mobilize tools and material to the site.

### 3.1.2 Strengths

Willows are abundant throughout most of the state and can survive in poor soils. Their fast rate of growth mitigates damage caused on an irregular basis when the BECS has a few years between events to recover.

Willow trunks reduce water velocity along the banks during high water events. This reduction in velocity can cause some sediment suspended in the stream to settle out of the water and accumulate on the bank.

Over time, live stakes increase their protective value to the bank as the willows root and grow. Because they are live, they can self-repair to a degree and require less maintenance than non-living biological structures.

Live stakes can be used to reinforce riprap or rock revetments extending the life of these structures by a procedure called joint planting. The procedure is the same as live staking; only the stakes are planted in voids between the rocks of an armored revetment. Live stakes help prevent armor from sliding down the slope of a revetment. This can be a problem when riprap is placed directly on geo-textile. In this case, the fabric makes a smooth failure plane for the stones to slide on. The presence of the stakes offers an impediment to motion anchored into the soil beneath the geo-textile. This form of installation is more labor intensive than live staking on an unreinforced bank and has higher labor costs.

### 3.1.3 Limitations

The main weakness of live staking is the limitation on placement. Live stakes cannot be placed underwater since the willows need sunlight and air to survive. This prevents live staking from being a method of mitigating erosion at the toe of the bank. Live staking is best used in conjunction with rock or a spruce tree revetment to protect the toe of the bank slope. Without such protection, the bank may be undercut rendering the live staking ineffective.

In coastal regions of the state, groundwater may be too salty for live staking to be effective. In the Yukon-Kuskokwim Delta and other low lying areas, low elevations prevent willows from growing in many places, however, on higher ground, even if the location is isolated and devoid of native willow growth, live stakes may take root and grow. If live staking is being considered where willows do not currently grow along the bank of the river, the site should be evaluated by a professional botanist to determine if willows could be a viable option at the site.

Live staking is susceptible to damage from ice scour. In streams laden with ice, scour may destroy the staking before it has had a chance to take root. In general, this susceptibility decreases as the willows mature and develop roots. Heavy ice loads may preclude the use of any form of BECS due to ice scour and should be considered carefully in the selection process.

## 3.2 *Brush Mats*

Brush mats are a type of biological erosion control structure that protects the bank with a matt of interwoven branches staked to the ground. The branches of the matt can either be dormant cuttings similar to cuttings used for live staking which will root or they can be dead cuttings intended to provide only structure. In either case, the mesh of branches reduces water velocity along the thereby reducing erosion. The mesh also acts as a trap for sediment and local seeds encouraging vegetation of the protected bank. Even if dead branches are used for the matt, growth may occur at the site due to this seeding. The toe of a bank protected by a brush mat should be protected by a spruce tree revetment, root wads or even rock in most cases. Typically, the bottom of the mesh is protected with a fascine bundle or coir log to act as a transition between the two methods and to prevent the bottom edge of the mat from unraveling.

Brush mats can be used along all river banks where cuttings can be anchored to the soil. In very low flow streams, it may be possible to extend the mat to the toe of the bank without further reinforcement. Live stakes can be used in some areas to increase the protective value of the revetment. Mats formed of live stakes are more resilient to damage because they can grow to cover areas damaged by high flow events. Materials are available throughout most of the state, and cuttings could be transported to sites with no native trees, though this would drive up the cost.

### 3.2.1 Cost

Cost for brush mats is difficult to normalize to a unit because the length of cutting and mesh density will vary from site to site. Streambank Revegetation and Protection (2005) reports a cost of $1.50 per stem for fat leaf willows. For cost comparison purposes, a mat is assumed to use 2 layers of stems at 6 stems per foot. Using Davis-Bacon wages for Alaska labor and production rates extrapolated from a project completed in 2008 on Cottonwood Creek, the cost to install brush mats is approximately $140 per square foot.

### 3.2.2 Strengths

Brush mats use relatively cheap materials that are widely available throughout the state and can be applied to most bank conditions, even locations where vegetation will not grow. When live materials can be used, the brush mat becomes more effective over time as growth produces more area to reduce water velocity and trap sediment.

### 3.2.3 Limitations

As with live staking, some limitations apply to the use of live materials in brush mats. Unlike live staking, however, a brush mat can still be effective when constructed of non-living members. When this is the case, the benefits of growth are not realized and regular maintenance will be required to repair minor damage that could be repaired by the growth of live members.

Brush mats are susceptible to damage from ice scour either through severing the twine that holds the mat to the bank or by scraping the mat off the bank entirely. If live members are used, this susceptibility decreases over time as root systems develop and branches grow and increase in diameter. Ice conditions need to be examined before a brush mat is installed at any site.

Except in shallow low flow streams, brush mats do not provide protection to the toe of the bank and require further toe reinforcement to be effective. This means that a brush mat is ineffective on its own in situations where the bank experiences undercutting below the water line.

## 3.3 *Spruce Tree Revetment*

Spruce trees can be used to form a protective revetment against a river bank. Before placement, the trees are harvested whole with the root wad cut off with special care taken to minimize damage to the branches. At the revetment site, the trees are placed horizontally along the bank with the tops facing downstream so that the tops of upstream trees cover the base of downstream trees (Figure 4.6). This placement allows the branches to flex with the current. Placing a tree in the opposite direction increases the likelihood that branches will be broken off the trees by high flow events or debris. The direction of the current at the bank should be accounted for when orienting the trees. In an eddy, trees should point upstream since the current at the bank flows upstream. The trees are tethered to the bank with cables attached to either dead men or earth anchors (Figure 4.7). Once installed, the trees will deflect some water flow away from the bank and reduce velocities within the branch matrix. The water velocity against the bank can decrease to the point that sediment settles out of the water and deposits into the branch matrix of the revetment. Since the spruce trees are not live features, they can be placed underwater providing protection to the toe of the bank.

Theoretically, spruce trees can be placed anywhere in the state since the trees do not need to be living to be effective. In practice, it is not practical to transport whole trees over long distances without causing excessive drying. Ice conditions on a river also limit the usefulness of this type of revetment as the cable tethering can be ripped out by large ice pans impacting against the trees. Spruce trees have a wide range in the state of Alaska with Sitka spruce covering the Pacific coastal regions of the state and black and white spruce covering the interior south of the Brooks Range.

### 3.3.1 Cost

Costs from Streambank Revegetation and Protection Manual (2005) are as follows:

Spruce tree: $13 - $50 per linear foot
3/16” Galvanized cable, 250’ spool: $110
Duckbill earth anchor: $10

Using these values, the cost per 100 foot of revetment can be roughly estimated with the following assumptions: Anchors are required every six feet with six foot embedment into the bank. Wire length required to secure the tree per anchor is 20 feet. Upstream trees overlap downstream trees for 40% of their length. That calls for 170 feet of tree, 340 feet of wire and 17 anchors. Using a tree cost of $50 per foot of tree, the total material cost for these quantities is around $8,800. Using these material costs, Davis-Bacon wages for Alaska and an assumption that a crew of four can install the materials in a ten hour shift, the cost of this type of project is about $100 per linear foot of bank per row of trees. Production rates will vary greatly depending upon bank conditions and access to the toe; it is easier to maneuver the trees into position when the banks are low and there is good footing at the toe while it will take much more time to move the trees to the toe of a tall bank and take longer if the riverbed offers poor footing. Also, this cost does not account for mobilizing materials and equipment to the site.

### 3.3.2 Strengths

Relatively cheap materials available in most of the state keep the costs of this type of structure lower in comparison to more hardened structures such as riprap and articulated concrete.

Spruce tree revetments can be placed at the toe of a bank to stabilize lighter upper bank erosion control structures such as live staking or brush mats.

### 3.3.3 Limitations

Trees and cables decay over time requiring maintenance every 1 to 3 years. Maintenance is performed by adding trees to the revetment when the existing trees lose their branch coverage. New trees are added in the same process as original trees were installed. Also, exposed anchors and cables must be removed. Loose cables in the water can pose a navigational hazard by wrapping around a prop and either snarling the motor and snagging the vessel or posing a life safety hazard if the cable snaps.

Tree branches and anchor cables are susceptible to damage from ice scour. While this does not preclude the use of spruce trees in ice laden streams, damage to the revetment will occur quickly resulting in an annual need for maintenance. For short term mitigation, this may be an acceptable burden.

A spruce tree revetment must be used to cover an entire erosion area. They cannot be used to strengthen one part. Unlike a rock revetment which can adjust to changing bank geometry, spruce tree revetments are completely dependent upon the strength of the soils in the bank. Once the foundation soils are compromised, the spruce trees will dislodge from the bank and float away. Floating debris from this sort of failure may pose a financial liability if structures downstream are damaged in an event.

## 3.4 *Root Wads*

Root wads can be used to protect the toe of the bank. The concept is similar to the spruce tree revetment, but instead of using the branch matrix of the tree to reduce water velocities against the bank, in this case, the root matrix performs the function. The root wads are anchored to the bank by burying the trunk of the tree into the bank and reinforcing the structure with logs and rocks as necessary.

### 3.4.1 Cost

The Alaska Department of Fish and Game reported the cost of a root wad projects in Alaska at Jim's Creek between $200,000 and $300,000 for 200 feet of bank protection. This comes to $1,250 per linear foot using a single layer of root wads using the median estimated value of the project. This cost is a total project cost and does include mobilization costs and does not directly compare to the other costs reported in this appendix.

### 3.4.2 Strengths

Root wads protect the toe of the bank when installed correctly and are fairly robust requiring less maintenance than spruce tree revetments.

### 3.4.3 Limitations

Root wad placement is one of the most expensive and complicated biological erosion control structure requiring extensive bank preparation. Heavy machinery is required for harvesting and placement of materials.

Placement of individual root wads is a critical issue. Incorrect placement can lead to aggravated scour which can quickly undermine the structure. Bank materials disturbed for the placement of the root wads may be more susceptible to scour than the original bank leading to an increase in the rate of erosion in the case of root wad failure.

## 3.5 *Coir Logs*

Coir logs are coconut fiber filled manufactured bundles held together in a biodegradable mesh. They can be purchased in many diameters and lengths though a 12 inch diameter and 20 foot length is fairly typical. Coir logs are used to protect the toe of a bank on low velocity streams and generally work best when the stream forming flow depth at the bank is less than the diameter of the log.

As a manufactured product, coir logs are not limited by a species' growing range. The primary concern in using the logs is whether or not they would be effective at a particular site.

### 3.5.1 Cost

As reported by Strembank Revegetation and Protection (2005), the cost of a 1 foot diameter, 20 foot long coir log ranged from $125 to $165. This cost represents 2004 data. Using production rates for a protection project completed in 2008 on Cottonwood Creek in the Matanuska-Susitna Borough, Davis-Bacon wages for Alaska and the above material cost, this type of project costs approximately $30 per linear foot to install. This cost does not include costs to mobilize tools and materials to the site.

### 3.5.2 Strengths

Coir logs are fairly light when dry and can be moved and installed by hand. No heavy equipment is required. Once wetted, the logs become very heavy and difficult to move.

### 3.5.3 Limitations

The material makeup of coir logs is completely biodegradable with an average life of 6 to 10 years preventing coir logs from being a permanent erosion control structure. In Alaska, some coir logs have lasted over 20 years, but this length of durability is not intended. Coir logs are better suited to protecting a bank while other BECS mature such as live staking and brush mats.

Coir logs are not resistant to physical impact and are not suited for use in areas where ice scour is a concern.

The size of a coir log is an extremely limiting factor. Since the extent of protection is limited to a fraction of the log's diameter, they are only suitable for use in low flow environments which tend not to be critically eroding areas.

## 3.6 *Access Control*

All of the above methods employ "soft" materials which are susceptible to breaking down under foot and vehicle traffic. To ensure a project lasts as long as intended, steps need to be taken to ensure that access to the bank is regulated. Access control is especially crucial in the first few years of growth for projects that use live features such as live stakes and brush mats. Several types of access control are available and provide differing levels of protection.

### 3.6.1 Signage

Signs are the least restrictive form of access control and can be as simple as a private property marker. The effectiveness of signage can vary from site to site but can be improved with the quality of information displayed. A simple "KEEP OUT" message may define the sign's objective, but also may be easily ignored. More effective signage engages the public and solicits their assistance in maintaining the project. Descriptions of project objectives or informational signs describing the site have been effective. Ultimately, signs are simply aides to help the public restrict itself from using the bank.

### 3.6.2 Barriers

Barriers physically impede the flow of traffic to the project site. Fences are effective in restricting pedestrian traffic. Fences also restrict the flow of snow and waterborne debris and may have unintended effects during flood events. A wood plank fence meant to keep traffic off a bank may double as a snow fence in the winter.

### 3.6.3 Access Walkways

Another way of protecting a project is to provide access to the river over the bank. Light penetrating walkways can be installed to take traffic to the river bank while preventing damage to vegetation. Good walkways for BECS are elevated and provide sufficient light penetration for the vegetation to grow beneath the walkway. Components are usually made from timber or aluminum. The layout of the walkway should accommodate the most prevalent use of the bank. If fishing from the bank is a normal practice, platforms can be constructed to keep anglers off the bank. These platforms are less useful when fishing is done by set net or dip net. Platforms are somewhat expensive to construct and are at risk from ice damage. Usually, platforms and walkways near the expected level of ice buildup are removed for winter months and replaced after break up.

# 4 Soil-Cement Sack Revetment

Soil-Cement sack revetments are similar to sandbag structures but are filled with a mixture of local soil and Portland cement instead of sand. The cement content of the fill can range from 8 to 20 percent. This mixture causes the material in the sacks to cure forming solid units that are not dependent upon the sandbag for containment. However, because the fill material is rigid, this type of revetment is very susceptible to settlement problems and can develop cracks easily. Revetments of this type can be designed to have a cement bond between sacks. This allows the revetment to act as a monolithic structure which can help if currents are strong or ice is a factor. This determination should be made on a site by site basis.

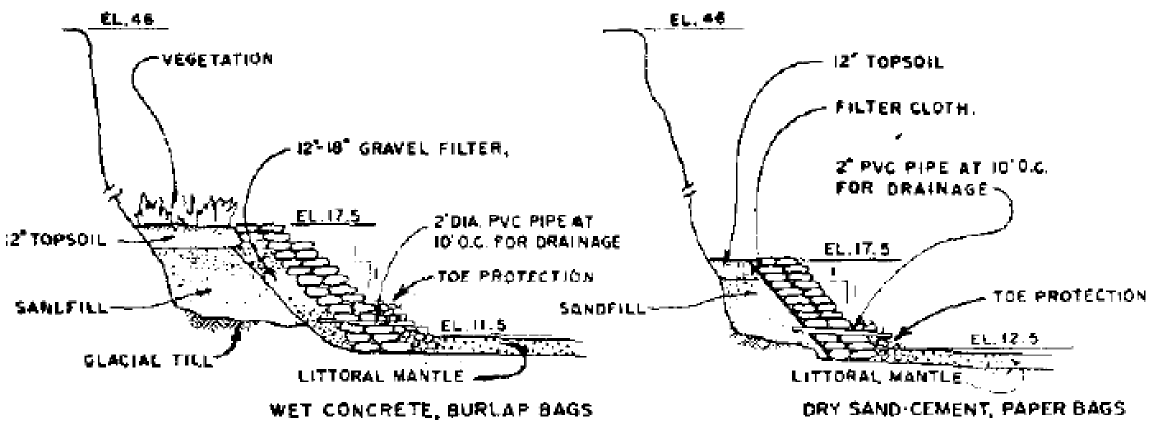


**Figure 4.1: Soil sack revetment sections used at Oak Harbor, WA.**

A soil sack revetment was used at Oak Harbor, WA to mitigate an erosion problem. The slope of the revetment was 1:1, and the structure held up reasonably from 1978 to 1995. It should be noted that this particular revetment received additional toe protection in the form of riprap and was placed on granular soils. Also, there is no ice present in Oak Harbor which would tend to cause more damage to the revetment.

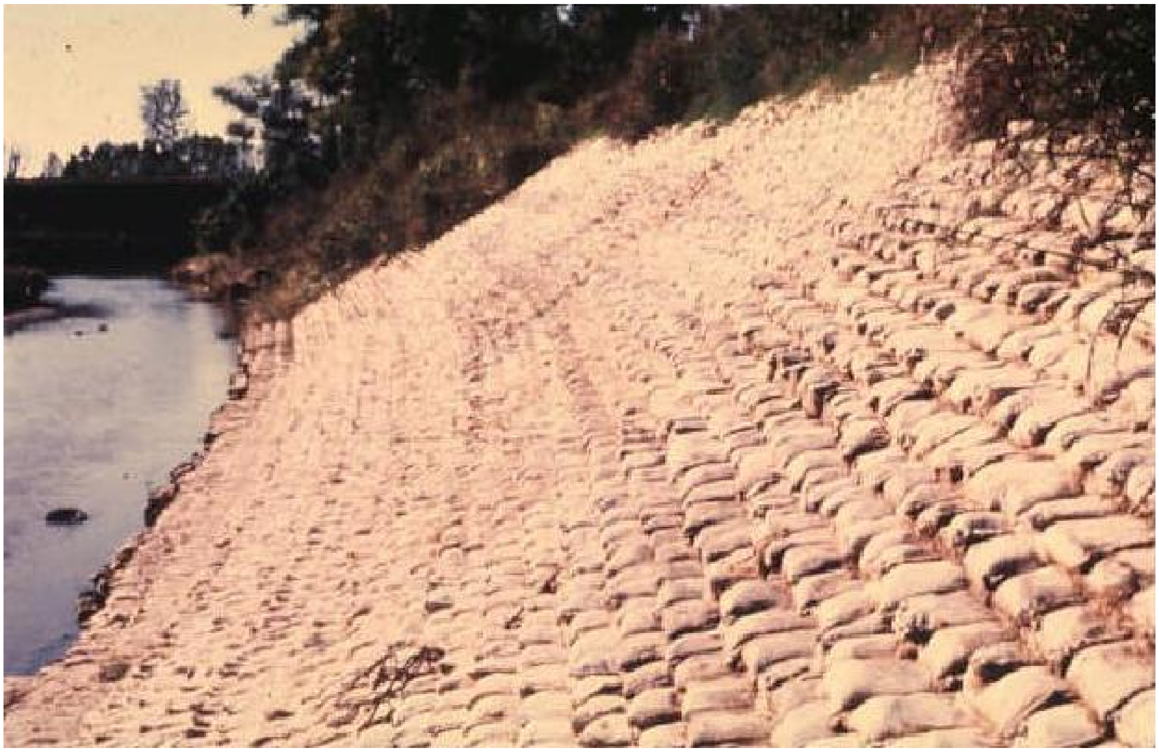

**Figure 4.2: Typical soil-cement sack revetment.**

## 4.1 *Cost*

The cost of filling and placing sandbags varies greatly from site to site. Ease of access affects how long it takes to place each bag and bank slope determines how many bags are needed per layer, affecting the coverage of each bag. For comparison purposes, it is assumed that it will take a two person crew 2 minutes to fill each bag and a single person 15 minutes to place each bag. An extra 2 minutes per bag is used to account for mixing the fill material stockpile. Coverage is assumed to be two bags per square foot which represents a bank of 2:1 using two rows of sacks per layer. Using these assumptions, material costs of $1.50 per bag and $0.50 of Portland cement per bag, and Davis-Bacon wages for Alaska, the cost of this type of project comes to around $40 per square foot. This cost assumes that fill material is free and excludes the cost of mobilizing equipment and crew.

## 4.2 *Strengths*

Soil-cement revetments are simple structures requiring no specialized construction techniques aside from mixing the soil-cement fill. Most of the construction can be performed without heavy machinery. Materials are readily available.

## 4.3 *Limitations*

Stability is a major concern for soil-cement sack revetments. While much emphasis during construction is placed on creating a bond between sacks, in practice this bond is weak and can be assumed to be zero when considering hydraulic and ice forces acting against the structure. Essentially, the revetment is a couple of layers of manufactured rocks which have smooth surfaces. The smooth surfaces make individual sacks prone to displacement when subject to high water velocities, much more so than riprap, and ice plucking.  Once the strength of the grout bond between sacks is overcome, the shape of the sacks offers little impediment to displacement,

Stacking sacks is a labor intensive effort requiring large amounts of people while construction progresses.  Because the fill material is moisture sensitive, entire batches of fill need to be used and sacks placed before laborers can be released to other duties or fill material may be wasted.

Before the soil-cement mixture sets, the sacks are susceptible to vandalism as a regular sandbag structure would be.  This may necessitate the use of watchmen in locations where vandalism is a problem.

Soil-Cement Sack revetments are rigid structures and do not adapt to changing bank geometry when a bond is used.  When flanking or settlement occurs with this type of structure, cracks will form creating paths for material behind the revetment to be pumped out.

When no cement bond is used, individual sacks may be more prone to ice plucking than rock due to their smooth surfaces.  Regular sack replacement may be required on a revetment that resists ice forces.

# 5 Methods to Avoid

Sometimes, erosion problems are acute and lead to ad-hoc solutions in the interests of constructing a project quickly. While some of these measures may be successful, many result in unintended consequences. Listed below are a few methods to avoid using. In most cases, they have been tried and found not to significantly protect the bank. In some cases, usage of these methods aggravates the problem.

## 5.1 *Automobile (Snowmobile) Revetment*

This type of revetment is created by placing used vehicles (cars, trucks, snow machines, etc.) on the bank to protect it from current impingement. Unfortunately, do to the complex shape of the vehicles, there is a tendency for the large bodies of the vehicles to direct current against the bank rather than armor it. This causes high velocity micro-currents to impact the bank at the boundaries of the objects causing a local increase in scour. Instead of mitigating erosion, this type of revetment can actually aggravate it, especially in fine grained soils that can easily be put in suspension.

## 5.2 *Tire Revetment*

Tires can be arranged in many ways to form bank protection, but a common one is to lash the tires together to form a protective mat. While the principle is sound, the tires are made of robust materials which are difficult to puncture and work with. Also there is the problem of anchoring the tires to the bank. If filled with soil, there is a risk of losing the fill to scour and having the revetment float away. Anchoring the revetment with cables and earth anchors quickly drives the cost up. Another problem using tires is that they are not readily available in large quantities in remote communities.

## 5.3 *Geo-textile Revetment*

This type of revetment is made by laying geo-textile over a bank and anchoring it with rocks or concrete blocks so that it will not float away in the current. A good use for fabric is as an underlayment to a riprap or quarry stone revetment to prevent the soil under the revetment from pumping out through voids between armor stones. On its own, however, the fabric is susceptible to tearing from river borne debris and ice. Once torn, material can be pumped out from behind the fabric at alarming rates.

# 6 Attachments

Streambank Revegetation and Protection

# 7 References

INDOT. "The Indiana Design Manual". Chapter 38. 2007.

Moore, Nancy J. and Muhlberg, Gay A.. "Streambank Revegitation and Protection". Technical Report No. 98-3. rev 2005.

Personal conversation with Dean Hughes, Habitat Biologist from Alaska Department of Fish and Game

USACE. "Engineering and Design - Design of Coastal Revetments, Seawalls, and Bulkheads". 1995. EM 1110-2-1614.

USACE. "Low Cost Shore Protection".1981.

USACE. "Slope Stability". 2003. EM 1110-2-1902.

USACE. "WES Stream Investigation and Streambank Stabilization Handbook". 1995. accessible at: http://www.tpub.com/content/coastalhydraulicslaboratoryfact/7_StreambankManual/index.htm

USDA National Resources Conservation Service. "Engineering Field Handbook".1996. 210-VI-NEH-650.