

Watershed Restoration Technical Bulletin

Streamline

Vol. 4 No. 4

Soil Bioengineering for Steep/Unstable Slopes and Riparian Restoration

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Introduction

Soil bioengineering is the use of living plant materials to perform specific engineering functions (Schiechtel, 1980). This method can be used to treat seepage zones and control erosion by stabilizing steep slopes (Gray and Leiser, 1982); it can also be used in construction and riparian restoration. Soil bioengineering fits well in the successional reclamation model developed by Polster (1989). Successional reclamation seeks to reintegrate the disturbed site into the natural successional processes that serve to vegetate sites. It is possible to develop systems designed to stabilize anthropogenic disturbances by investigating how natural revegetation systems stabilize natural disturbances (Polster and Bell, 1980; Straker, 1996). Certain pioneering species that are found on naturally disturbed sites have the ability to root from cuttings, to grow following burial, and to grow under harsh conditions: these characteristics make such species useful for soil bioengineering.

The first step in the development of an effective soil bioengineering program is the identification of site features that are limiting growth of vegetation. Polster (1991) identified five key vegetation limiting features: steep slopes, adverse texture/compaction, poor nutrient status, adverse chemical properties and soil temperature extremes. Of these, steep slopes, adverse texture/compaction and poor nutrient status are often associated with forest landslides.

Steep slopes are by far the most common vegetation limiting factor on landslide sites. Slopes in excess of the natural angle of repose for the material in question will typically be too steep for effective vegetation growth. For most materials, slopes of 35 to 40 degrees represent the natural angle of repose. Some materials such as saturated silts fail at slopes of less than 10 degrees. Slopes above the natural angle of repose will continually fail and will therefore limit growth of vegetation; slopes at

Continued on page 2

Editor's Notes

Please note that there was an error in the ledger of Figure 1 on page 26 of the last Streamline Volume 4 No. 3: squares = parr, circles = smolt and triangles = total number of parr and smolt.

Several months ago a reader recommended an article on soil bioengineering and this issue is the result of that e-mail. As all three feature articles have a technical component, we have not included a separate Tech Tips in this issue. The next issue of Streamline which is expected to be released this summer will contain the abstracts from the recent Interior Forest Site Rehabilitation Workshop.

Please consider providing Streamline with technical perspectives. "Perspectives" will be a new column included in Streamline, a chance for practitioners to put your opinion forward on some of the less tested or more controversial techniques, ideas, and components of watershed restoration. See the back page of this issue for Streamline's contact information.

This Quarter

Winter 1999 / Spring 2000

Feature Articles

Soil Bioengineering for Steep / Unstable Slopes and Riparian Restoration

Hillslope Restoration - Biotechnical Soil Stabilization Demonstration Sites

Seeding for Site Rehabilitation

Insert

Abstracts from the Coastal Forest Site Rehabilitation Workshop

Update

Feature

or below the angle of repose will be reasonably stable and will support vegetation growth.

Adverse texture/compaction can hinder or preclude vegetation establishment and growth. Soils that are too coarse will not hold moisture or nutrients essential for plant growth. In general, the seedling stage of plant growth is the most sensitive to adverse texture/compaction. Fine textured soils such as compacted silty clay tills can prevent the growth of vegetation by limiting the extent of root penetration.

Associated with many sites, poor nutrient status can also severely limit plant growth. Most sub-soils have very limited nutrients and will not adequately support plant growth other than species such as alder. Salvage and subsequent re-use of "topsoil" will help to retain nutrients on the site. However, even where attempts are made to retain topsoil for use in reclamation, soil mixing and loss of structure can result in nutrient-deficient sites.

In addition, a combination of these factors may affect plant growth. A 40° loose shale slope with no fine textured soils may limit plant growth by continually raveling and sliding, as well as by becoming very dry in the summer. Similarly, a calcareous silty clay slope that is continually "flowing" in the spring may limit vegetation growth both by the movement and by the lack of nutrients associated with a high pH. In these cases, it is essential to address all of the factors that combine to limit growth.

Many of these growth-limiting factors can be treated with soil bioengineering systems. For example, such treatments can be designed to effectively reduce slope angles relative to the growth of vegetation without actually changing the overall slope. Similarly, soil bioengineering techniques can be used to drain excess moisture that may be creating slope instability. Certain techniques can also be used to control erosion along watercourses, prevent raveling of angle of repose on fill slopes, and reinforce earth fills to create a cohesive mass that resists movement.

Plant Materials for Bioengineering

Pioneering woody species are of particular importance in the development of soil bioengineering systems and play a key role in successional advancement of the site. This group of plants represents the successional bridge between the herbaceous initial colonizers (seeded grasses and legumes) of a disturbed site and later seral types. Pioneering woody species perform important functions in the natural restoration of damaged sites: they can stabilize, provide erosion protection, and offer site amelioration. Since pioneering

woody species are often associated with rhizobia that fix nitrogen, they also improve the site's nutritional status (Binkley et al. 1982). Roots from the plants used in the soil bioengineering structures will provide substantial reinforcement of the soils. For birch (expected to be similar to willow), measurements indicate root tensile strengths of 464 kg/cm² for root sizes less than 2 mm. For the same root size, spruce and hemlock roots were found to have a strength of 102 kg/cm² and coastal Douglas fir roots were found to have a tensile strength of 578 kg/cm². Hence, the root strength of the rapidly growing pioneering species used in soil bioengineering can partially replace that lost due to harvesting activities.

Stem cuttings of many species can be used for soil bioengineering although willows, red-osier dogwood and cottonwood are most effective. For maximum growth, cuttings from woody vegetation should be collected in the fall and winter while the plant is dormant so that stored photosynthates (carbohydrates) are at their highest level. This stored energy allows the cutting to begin fresh growth in the spring and early summer without further photosynthesis.

New roots and shoots on the cuttings develop in two ways. Axillary buds develop in the leaf axils, and "adventitious" buds (Hartmann and Kester, 1975) develop from other tissues such as the cut end of the stem in a process termed dedifferentiation. Cuttings with as many axils as possible should be used to maximize the amount of growth from axillary buds. In some cases, wounding the stem may encourage adventitious bud formation. When plants have been wounded (cut), callus typically forms, possibly developing from the vascular cambium (just under the bark) or even the epidermal tissues. Although adventitious roots often appear to arise from under this callus tissue, the formation of callus and the formation of roots are generally independent (Hartmann and Kester, 1975). Adventitious buds may therefore form at any location where these tissues are present. In some species that are easy to root, preformed (latent) bud initials develop with the initial growth of the stem. This adaptation, along with several others, allows such species to function well in soil bioengineering systems.

Care is necessary in handling cuttings for soil bioengineering. Ideally, cuttings should be planted directly after collection, to avoid problems associated with storage. If cuttings must be stored, they should be kept moist and at temperatures that minimize respiration (-1° to -4° C). It is best to collect cuttings from healthy, growing parent plants, but avoiding the tips of stems. Such cuttings will perform better than those collected from decadent, senescent stems. Local

Ministry of Forests officers can provide advice on appropriate locations to collect cuttings. When collecting, it is important to take care to avoid environmentally sensitive sites such as streambanks or areas of heavy ungulate use. Direct planting of root cuttings may be used to establish some species. Although collecting and using of root cuttings is significantly more difficult than using stem cuttings, there are cases (e.g. Aspen) in which root cuttings provide the best results and stem cuttings are not effective.

Bioengineering Systems for Water Management

Live Pole Drains

Live pole drains (Figure 1) provide a preferred flow path for water sites where excess soil moisture is causing instability. These drains are constructed of bundles of living cuttings that are placed in shallow trenches to intersect and collect the moisture. The bundles should be a minimum of 30 cm in diameter, and tied as tightly as possible, although careful trimming of the cuttings is not required. They are lightly buried with local materials, leaving some of the cuttings unburied on the top of the bundle. The plants (typically willows) used to form the bundles sprout and grow, and the moisture continues to drain from the lower end. The growth from the live pole drains forms the initial cover on the seepage site, which then allows other species to invade. As with other soil bioengineering systems, live pole drains must be designed to suit the specific conditions of the site. Live pole drains typically grow into a dense stand of hydrophytic vegetation; that is exactly what nature would produce, given enough time. Thus, this technique fits well in the successional reclamation scheme.

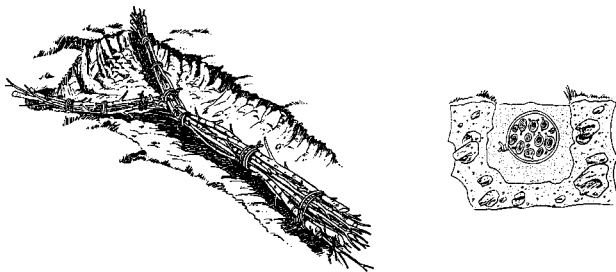


Figure 1. Live pole drains can be used to stabilize slumping soils. This view shows the layout of live pole drains in a slump, with some twigs from the bundles left above ground. The covering soils have been removed for clarity. The section shows a typical covering.

Live Silt Fences

Live silt fences (Figure 2) are used to reduce sediment movement on low gradient streams. Whereas live gully breaks can be used on very steep gullies and

streams, and live bank protection can be used on larger streams and rivers, live silt fences are used on very small watercourses with lower gradients. Live silt fences consist of rows of cuttings placed into the bed to slow water velocities and cause sediments to be deposited. These rows of cuttings also trap floating debris that further slows water velocities. Once the cuttings grow, the water flows between the stems of the growing cuttings, creating a brushy, swampy area characteristic of natural seepage areas and small streams.

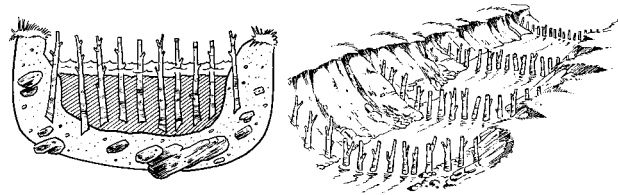


Figure 2. Live silt fences can be used to provide a willow coppice in small streams and ditches. These fences slow the velocity of the water and allow sediments to settle out. In each band, the cuttings can be either in single rows (as shown) or multiple rows.

Willow and cottonwood cuttings are particularly useful for live silt fences, as these species will continue to grow when their stems are buried. Live silt fences can be established in swales and small drainage channels along roads, and in gullies on deactivated roads. This assists in restoring the sites. Rather than continuing to erode, these small channels can act as sediment traps and provide clean water to downstream sites. The natural filtering ability of deciduous brushland can be recreated using live silt fences on the small drainages and seepages on forest lands. When live silt fences are used, note that care must be taken to ensure the hydraulic integrity of the drainage system.

Live Bank Protection

Live bank protection (Figure 3) consists of wattle fences built to protect the bank from the scouring action of streams. These structures provide a means of stabilizing stream banks that may have become destabilized by debris torrents or through the growth of nick points related to harvesting. The typical arrangement for live bank protection provides structure on the bends of the stream where undercutting is occurring or may develop. The structures are arranged so that the upstream ends are located at the tangent point between opposing curves. The ends should be tucked well into the bank to avoid "catching" the flow and causing more erosion. When backfilling the structures with local materials, take care to avoid large cobbles and boulders that will tend to be dry in the summer. Growth of the live bank protection structures

Feature

provides a cover of riparian vegetation along the streams. The willows and cottonwoods used in the structures provide a strong network of roots that help to hold the streambank in place.

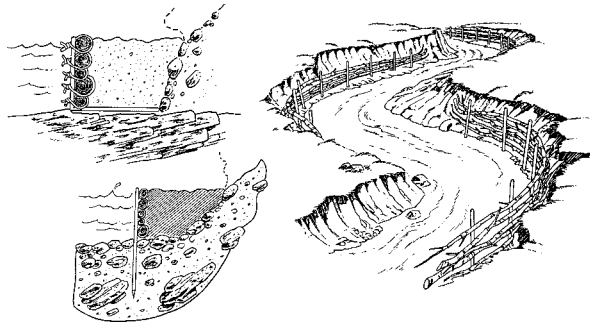


Figure 3. Live bank protection can be used to control erosion on the outside of curves. Typically, the undercut bank would be resloped to backfill the structures. Live bank protection can be used where the stream has eroded the materials down to bedrock or where unconsolidated materials are still present. Backfill is shown in these sections and the undercut banks have been resloped.

Live Gully Breaks

Live gully breaks (Figure 4) are large wattle fences built in gullies to control the flow of water. These structures are established high in the channel where gully torrents originate, often from minor collapses of gully sidewalls. In gullies that have already tormented, live gully breaks can assist in revegetation and stabilization by providing sites where materials may be trapped and where vegetation can become established. As with any soil bioengineering system, live gully breaks will strengthen with age.

Live gully breaks will trap materials that would otherwise serve to initiate a debris torrent or contribute sediment to streams. The physical structure will serve this purpose initially, while the growth of the cuttings and the establishment of rows of willows will provide

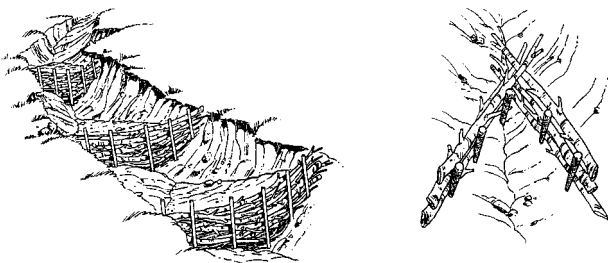


Figure 4. Live gully breaks slow the velocity of water movement down a gully and thus trap sediments. In narrow gullies (right) the cuttings are crossed at the back of the gully while in wider gullies (left) the structure is like a wattle fence. In both cases care must be taken to ensure the water flow stays in the gully.

long-term control of materials. Willows will continue to grow even when deeply buried and will reinforce the soil through the growth of roots. Live gully blocks create numerous small structures in the ditches or high on the slopes; these are preferable to massive engineered structures that trap debris down below. Many soil bioengineering systems use such a "strength in numbers" concept to create some very strong stabilization systems.

Live Staking

Live staking (Figure 5) is perhaps the simplest form of soil bioengineering. Live staking is the use of living cuttings to stabilize slumping materials or to "pin" sods to a slope. Live staking is useful in silty materials that tend to flow down the slope in the spring. In these cases, the cuttings are inserted into the soft materials in the spring; as the cuttings grow over the summer, the roots bind the unstable materials and prevent further flows.

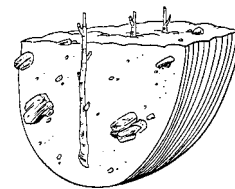


Figure 5. Live staking is a simple method of establishing pioneering woody vegetation. It can be effectively used on "flowing" silts and to establish riparian vegetation along streams.

The cuttings used in live staking should be at least 40 cm long by 2 cm in diameter. They should be inserted into the soil so that at least three-quarters of the length of the cutting is underground. On drier sites, seven-eighths of the cutting should be inserted. Cuttings need not be planted vertically (as shown) but can be slipped into the soil diagonally, as long as the cutting will remain moist over most of its length. Cuttings should be planted with the distal (top) end up. It may be useful to leave short stubs of branches on the cutting (as shown) to indicate which end is the top. The spacing between cuttings will vary depending on the materials, but can be as little as 10 cm. On flowing silts, spacings of about 20 cm work well.

Bioengineering Systems for Steep Slopes

Wattle Fences

Wattle fences (Figure 6) are short retaining walls built of living cuttings. The walls take up the vertical component of the slope, reducing the effective slope angle and allowing vegetation to become established. The living cuttings sprout and grow, further strengthening the structure. Wattle fences are used where site moisture conditions will allow the living

Feature

cuttings on the face of the fence to sprout and grow. Wattle fence installations are appropriate at sites with fine textured soils or where seepage of groundwater can provide ample summer moisture.

Wattle fences can provide support for oversteepened cut and fill slopes and for small soil slumps where excess soil moisture results in small rotational failures of surface materials. In the case of slumping sites, the wattle fences allow moisture to drain through the face of the fence while the soils are retained behind the fence. Where slumps are particularly wet, the branches and twigs may be retained on the cuttings to provide additional support for the wet soils. Wattle fences can be used to support slumps in combination with live pole drains that provide drainage of the excess moisture.

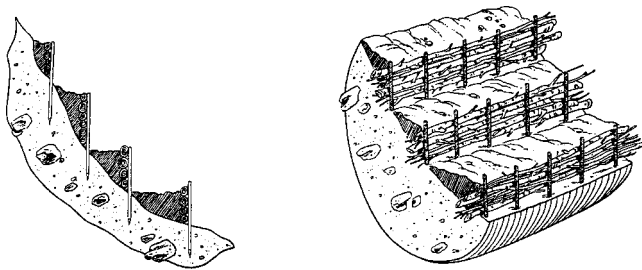


Figure 6. Wattle fences are short retaining walls constructed of living cuttings. They are used to provide slopes, which will support plant growth where oversteepened slopes are preventing plant establishment. The section shows the effects of steeper slopes on wattle fence spacing.

Modified Brush Layers

Modified brush layers (Figure 7) are brush layers supported on a small log or board (2 m in length by at least 5 cm in thickness). The board or log supports the brush layer and creates a small terrace to "catch" rolling rocks that would otherwise continue rolling down the slope, gathering speed and damaging vegetation. By the time the supporting log or board eventually rots, the cuttings will have grown enough to stabilize the slope. As the cuttings in the brush layer grow, the wall of plants will trap rocks and soil, preventing movement of materials down the slope. Reinforcing steel bar (rebar) one metre long by 15 mm diameter has been found to be the best support to hold the modified brush layers in place. Modified brush layers can be used on sites that would be too dry for effective wattle fence growth, but where some form of additional support is needed to stabilize the slopes. In addition, these structures can provide effective support for over-steepened cut slopes and sliver fills.

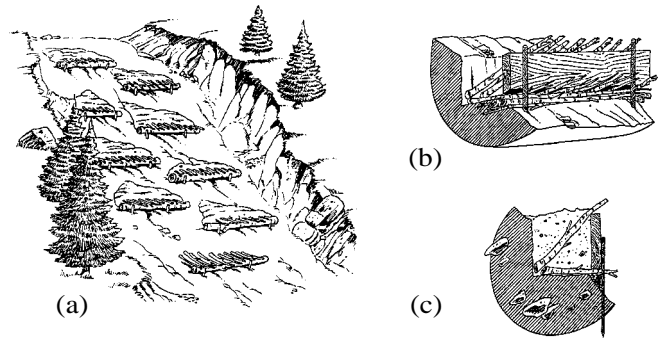


Figure 7. Modified brush layers can be built with either a log or a board for support. They should be staggered across a slope (a) so that material rolling down the slope doesn't have a chance to get going before it is caught. The detail (b) shows a modified brush layer prior to backfilling, while the section (c) shows the normal backfill which creates a bit of a bench.

Brush Layers in a Cut

Brush layers in a cut (Figure 8) are horizontal rows of cuttings (40 to 50 cm long) buried in the cut (in-situ materials) slope. In cuts or native ground, brush layers are constructed by digging a trench across the slope and installing the cuttings. The cuttings should have at least three-quarters of their length in the ground, or seven-eighths if the site is dry. Like most soil bioengineering systems, brush layers in a cut are built from the bottom of the slope so that the second trench excavation can be used to backfill the first, and so on, up the slope. The wall of plant materials established with a brush layer can act to control movement of materials from slopes.

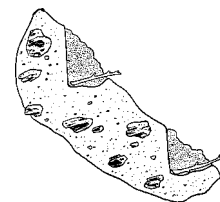


Figure 8. Brush layers in a cut can provide a row of living plant materials and assist in preventing movement of surface materials.

Bioengineering Systems for Soil Reinforcement

Brush Layers in Fill

Brush layers in fill (Figure 9) are horizontal rows of cuttings buried in a fill (such as a pulled back road) as the fill is constructed, to strengthen the fill material where roads are being deactivated or newly built. In some cases, fill materials must be placed on steep (1.5:1 or greater) angles due to the geometry of the site. In these cases, cuttings (2 to 5 m long) can be

Feature

inserted into the fills as they are constructed; these can assist in creating a cohesive mass from the fill material. When local overstepping of the fill is required, for example where gullies cross roads that are being deactivated, the development of brush layers in fills may be particularly useful. This will provide stability to the fill and will eventually result in the development of shrubby vegetation along the gully. Scheduling requirements for the use of cuttings may dictate that machine work be organized for these sites during seasons when cuttings can be used.

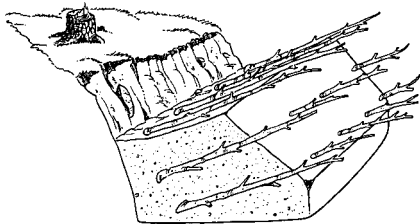


Figure 9. Brush layers in fill can act to reinforce the fill material. Full length cuttings can be used and can be expected to root along their entire length.

Live Reinforced Earth Walls (LaREWs)

Live reinforced earth walls have been developed to treat sites where piping or waterfalls have created a large cavity in the slope that must be refilled to stabilize the slope. Such sites would normally be backfilled with rock. However, the cost and, in some cases, the lack of access, calls for a different technique. When a large amount of fill is required to treat these sites and it is not possible to effectively compact the fill, the result is a slope that could easily fail again. In some cases, water flowing over a harder material (e.g. compacted till) may cut a large overhang when it hits a softer material (e.g. fine silts). Without effective stabilization, such a stream would continue to cut until the slope above collapses and the failure is repeated.

The use of traditional wattle fences for large undercut sites results in too much weight on the fences and the



Figure 10. Live reinforced earth walls are constructed with a wattle fence on the face and long cuttings going back into the slope to hold the face in place. Re-sloping the overhang provides the backfill while the LaREW provides a vegetated cover on the undercut area.

failure of the entire backfill. Most other options for such sites entail hard engineering and associated large costs. A simple alternative to these hard engineering solutions is the use of LaREWs, based on the traditional mechanically stabilized earth wall. Figure 10 shows the current design for LaREWs.

Live Smiles

Live smiles are used to treat sites where flowing mud prevents growth of vegetation. Fine silty lacustrine or morainal deposits can experience surface flows during spring break-up, with the underlying materials remaining firm. When this material is exposed in a cut, weathering of the surface leads to surface flows, eventually expanding until a change of material is encountered. Typically only the surface 10 cm or 15 cm actually flows, but when the surface covers several hectares, a large quantity of saturated material can end up at the bottom of the slope.

Willow cuttings are very strong in tension, and therefore a structure in which the plant materials are placed in tension would take advantage of this attribute. "Suspending" the mud with the willows in the form of a catenary curve (a "Golden Gate Bridge" form) places the willows in tension. Live smiles are designed to form such a catenary curve, with the ends firmly secured (Figure 11).

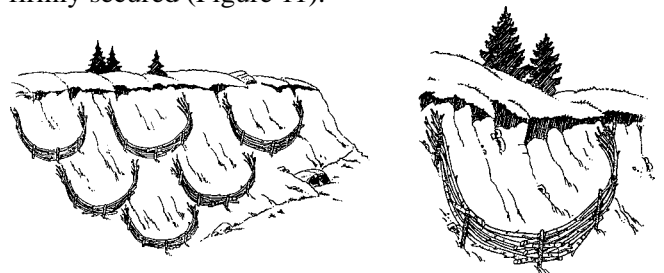


Figure 11. Live smiles have been designed to "suspend" flowing mud on the slope. They use a catenary curve much like a suspension bridge. With good anchors at the top ends, the cuttings are placed in tension. Live smiles are arranged in staggered rows of individual units (left). This uses the "strength in numbers" concept to create a strongly supported slope. The live smiles hold the mud back while allowing water to pass through the face.

Bioengineering Systems for Riparian Restoration

Live Gravel Bar Staking

Live gravel bar staking was developed in response to a need to treat streams and rivers where upslope landslides and erosion has resulted in significant sand and gravel deposits in the channel. Such deposits lead to stream bed de-stabilization as the watercourse re-works

alluvial deposits that had been inactive since glaciation. In some extreme cases, the de-stabilized stream channel deteriorates from a single channel with significant fish habitat complexity to a braided channel with little or no habitat diversity.

Traditional treatments, including physically digging out the channel and rip-rapping the banks, are normally only carried out in situations in which the excess sand and gravel threatens to cause destruction of property (usually bridges or roads). These treatments may cause decreased stability as the stream “headwalls” or fills in the void where the gravel was removed. Sometimes structures such as rock weirs or large woody debris are used in an attempt to capture some of the gravel. These structures tend to get overwhelmed by the massive amounts of gravel that may move in a system in a single year. In all of these traditional treatments, a significant investment must be made both initially and for many years after.

The primary problem with most sand and gravel bars is that the upper 30 cm or 40 cm gets very dry in the summer as the free draining substrate bakes in the summer sun. For little seedlings this is often the period of greatest stress. However, growth is assured by placing cuttings down to the water table, or at least well into the gravel (Figure 12). The clumps of cuttings mimic natural clumps of woody vegetation, trapping driftwood and creating a flow disruption that causes sand and gravel deposition. Sediment capture rates between 4,000 m³ and 8,000 m³ per hectare have been noted for a trial site on the San Juan River on the west coast of Vancouver Island during the first year after installation. An additional 3,000 to 4,000 m³ of sediment per hectare was collected at this site during the second winter season.

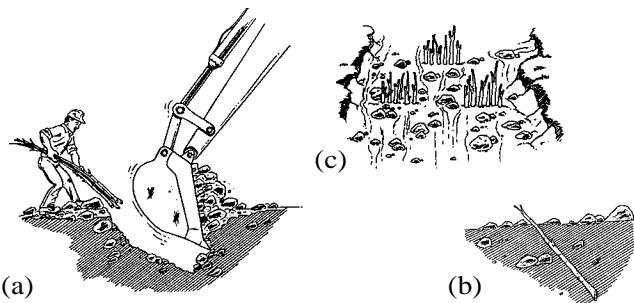


Figure 12. Live gravel bar staking (a) (b) gets the cuttings well down into the gravel bar to reach the water level. Where substrates are coarse, an excavator can be used to get the cuttings into the gravel. This work should be conducted under the supervision of a fisheries biologist. Clumps of live cuttings (c) mimic natural patterns and are believed to be best for collecting the maximum amount of sediment. These clumps disrupt the flow patterns, causing sediment to be deposited.

Live Shade

Live shade provides a vegetative cover for newly constructed fish habitat that is often created in back channels and off-channel areas to mitigate losses associated with historic impacts. This new habitat may involve excavations into the groundwater table to create permanent ponds and channels and, where sufficient flow is available, new spawning habitat. Construction of this new habitat clears large areas of riparian vegetation and generates a significant amount of spoil material that must be disposed of. The normal solution is to plant new vegetation in the area that has been cleared and used for spoil disposal. Placement of shade over the channels and waterways depends on the orientation of the site relative to the path of the sun. Where hundreds of metres of new channel have been created, the cost of revegetation using large stock can easily exceed the cost of the initial channel construction. Willows offer a potential solution to the fish habitat revegetation problem, as they root readily wherever moisture is available, and send up numerous new leafy shoots. However, unsupported willow cuttings could easily be blown over in the wind or be knocked down under snow. A tripod design was developed to provide firm support for the above-ground portions of the structure (Figure 13). The basal (butt) ends of the cuttings need to be placed well into the groundwater table (40 cm to 50 cm) adjacent to the newly constructed watercourse. Overlapping the basal ends of the cuttings

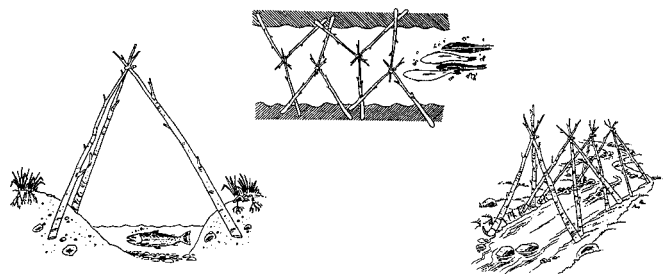


Figure 13. Live shade is designed to provide over-hanging riparian vegetation on newly constructed fish habitat. The structures will send up numerous new shoots while the butt ends of the cuttings will root in the moist soils on the banks. The basal ends of the cuttings used in live shade construction should be inserted well into the banks of the new channel. The key to avoiding a severe root-to-shoot imbalance is to ensure that the basal ends are within the groundwater zone. The tips should be tied together with binder twine or straps. The legs of the tripod forming the live shade should be adjusted so that the slope of the cuttings is at least 45°. Overlapping the basal ends of the tripods used for live shade can be used as a means of controlling how much cover is afforded by the structures. A dense lattice work of living willows will provide more complete canopy closure than an open structure. Hence, live shade can be used to regulate water temperatures.

Feature

allows a dense lattice of willow to be constructed. The length of the cuttings depends on the channel to be spanned; however, where cuttings are greater than about 4 m long, their flexibility becomes a problem. If active, beavers may limit the success.

Conclusions

Soil bioengineering can be an effective tool for the treatment of unstable slopes and riparian areas. Treatments are relatively inexpensive and can provide significant benefits in terms of reduced maintenance, reduced erosion and enhanced stability. As living systems, soil bioengineering systems need little or no maintenance and continue to strengthen over the years. Soil bioengineering can provide a bridge between traditional engineering treatments and normal seeding work, and can be useful in the reclamation of difficult sites.

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Hillslope Restoration - Biotechnical Soil Stabilization Demonstration Sites

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The Ministry of Forests (MOF) and the Ministry of Environment Land and Parks (MELP) have in recent years developed demonstration sites in Kingfisher Creek and Cooke Creek, south east of Salmon Arm (Figure 1). Kingfisher and Cooke Creeks are tributaries to the Shuswap River, which in turn flows into Mara Lake, Shuswap Lake, and into the South Thompson River. Demonstration values developed by MELP at four sites in the Kingfisher watershed include off-channel, instream, and bank stabilization techniques.

The Ministry of Forests has focused on upslope biotechnical soil stabilization techniques at three

demonstration sites in the Cooke Creek watershed. Work and monitoring in the three sites has been ongoing since 1997. Various innovative techniques have been tried at the sites, and lessons have been learned through informal monitoring and evaluation.

The first site involves the restoration of a landslide downslope from the Cooke Creek Forest Service Road (FSR) at 4km. This landslide occurred in the spring of 1997 and covered approximately one and one half hectares. The initial failure was on 60% unstable slopes, approximately 200 meters above the creek. The slide path continued down to, and into, the creek.