Proceedings of the 21st Annual British Columbia Mine Reclamation Symposium in Cranbrook, BC, 1997.
The Technical and Research Committee on Reclamation

RESTORATION OF LANDSLIDES AND UNSTABLE SLOPES: CONSIDERATIONS FOR BIOENGINEERING IN INTERIOR LOCATIONS

David F. Polster, M.Sc., R.P.Bio

Polster Environmental Services
5953 Deuchars Drive
Duncan, B.C.
V9L 1L5

ABSTRACT

Restoration of landslides and unstable slopes can provide significant challenges. Steep slopes, low fertility levels, unstable soils, compacted tills, flowing silts and other adverse conditions are typical of many forest landslides. Successional reclamation (Polster, 1989) and soil bioengineering (Schiechtl, 1980) can be used to provide a self-sustaining vegetation cover on many forest landslides and unstable slopes. This paper presents techniques that can be used in the restoration of these sites. Special considerations for the use of these techniques in Interior locations are presented. Examples are drawn from the author's experience.

INTRODUCTION

Bioengineering can provide an effective means of treating problem sites. Bioengineering is the use of living plant materials to perform some engineering function, whether it be simple erosion control with grass and legume seeding or more complex slope stabilization with willows and other plants (Schiechtl, 1980). Bioengineering can be used to stabilize steep slopes to treat seepage zones and to control erosion (Gray and Leiser, 1982). Bioengineering can also be used in construction to provide soil reinforcement and as living retaining walls.

Bioengineering fits well within the successional reclamation model developed by (Polster, 1989). Successional reclamation seeks to reintegrate the disturbed site into the natural successional processes which would serve to vegetate the site eventually. By investigating how natural revegetation systems stabilize natural disturbances (Polster and Bell, 1980; Straker, 1996), systems designed to stabilize anthropogenic disturbances can be developed. Bioengineering uses the same pioneering species that are found on naturally disturbed sites. Characteristics of these species such as the ability to root from cuttings, continued growth following burial and the ability to grow under harsh conditions all serve to make these species useful for bioengineering.

The first step in the development of an effective bioengineering program is the identification of those site features, which are limiting growth of vegetation. Five key vegetation limiting features were identified by Polster (1991) 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.

By far the most common feature limiting vegetation growth on forest sites is steep slopes. 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 in the 35 to 40 degree range 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 the growth of vegetation while slopes which are at or below the angle of repose will be reasonably stable and will support vegetation growth.

Adverse texture/compaction can significantly hinder 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. A young seedling growing in a pile of boulders at the base of a talus slope will not do well during the hot, dry days of July. However, a mature tree growing in the same boulders may do quite well with its roots well down in the soil below the rubble (Polster and Bell, 1980). Fine textured soils such as compacted silty clay tills can prevent the growth of vegetation by limiting the extent of root penetration. Adverse texture can slow or preclude vegetation growth.

Poor nutrient status associated with many forest sites can severely limit plant growth. Most forest sub-soils have very limited nutrients and will not support much in the way of plant growth except species such as alder which are associated with nitrogen fixing bacteria and can thus bring their own nutrients to the site. Salvage and subsequent use of "topsoils" will serve to retain nutrients on the sites. However, even where attempts are made to retain topsoils for use in reclamation, soil mixing and loss of structure can result in nutrient deficient sites.

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

Bioengineering systems can be used to "treat" many of the growth limiting factors found on forest sites. Treatments can be designed to effectively reduce slope angles relative to the growth of vegetation without actually changing the overall slope. Similarly, bioengineering techniques can be used to drain excess moisture that may be creating slope instability. Bioengineering techniques can also be used to control erosion along watercourses and to prevent ravelling of angle of repose fill slopes. Some bioengineering techniques can be used to reinforce earth fills and thus provide a cohesive mass that resists movement. This paper explores the use of bioengineering systems on Interior forest sites.

PLANT MATERIALS FOR BIOENGINEERING

Pioneering woody species are of particular importance in the development of bioengineering systems. This group of plants represents the successional bridge between the herbaceous initial colonizers (seeded grasses and legumes) of a disturbed site and later serai types and thus plays a key role in successional advancement of the site. Pioneering woody species perform important functions in the natural restoration of damaged sites such as stabilization, erosion protection and as wildlife browse. Pioneering woody species are often associated with rhyzobia, which fix nitrogen, and thus they serve to improve the nutritional status of a site (Binkley et al. 1982).

Stem cuttings of many species (Table 1) can be used for bioengineering although willows and cottonwood are most effective. Cuttings should be collected while the plant is dormant. Cutting woody vegetation in the fall and winter results in the maximum amount of growth. At this time of year, carbohydrate (stored photosynthates) are at their highest level in the plants. This allows the cutting to provide fresh growth in the spring without the benefit of further photosynthesis. Cutting woody plant stems in the fall and winter allows all of this stored energy to be expended in the growth of new roots and shoots during the spring and early summer.

TABLE 1

Some Useful Characteristics of Pioneering Woody Species

Species	Seed Numbers/Kg. (X 1,000)	Site Preferences (N Fixing)	Establishment
Sitka Alder	2,514	mesic - moist N fixing	from seed, not cuttings
Red Alder	1,468	mesic - moist N fixing	from seed, not cuttings
Red-osier Dogwood	30 - 58	moist, riparian	from seed, cuttings & rooted stock
Wolf Willow	7.5	dry, well drained N fixing	from seed & stem cuttings
Cottonwood	6,684 *	moist to wet	from seed & cuttings
Aspen	7,936	mesic to dry	from seed & root cuttings
Willow .	4,400 - 6,600	mesic - moist - wet	from cuttings

* Seed number for the related *P. grandidentata.*

New roots and shoots on the cuttings develop either from buds, which developed in the axils of the leaves (axillary buds), or from other tissues in a process termed dedifferentiation. Buds arising from these are termed "adventitious" buds (Hartmann and Kester, 1975). Axillary buds result in the growth of new shoots and roots from sites where there were leaves on the plant in the past. Adventitious buds result in the growth of new shoots and roots from either axillary locations or from other areas on the plant such as the cut end of the cutting. The growth of shoots, which develop, from axillary buds can be maximized by maximizing the number of such buds on the cutting. The encouragement of adventitious bud formation can be enhanced in some cases by wounding the stem. Callus typically forms when plants have been wounded (cut), and may develop 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, such as willows, which are very easy to root and widely used for bioengineering, preformed (latent) bud initials are formed as the stem develops initially. These species have a variety of adaptations, which allow them to function well in bioengineering systems. The presence of preformed bud initials is one such adaptation, and allows these plants to regrow effectively from cuttings and after being buried.

Scheduling of bioengineering projects where cuttings are to be used to coincide with optimal collection periods allows the cuttings to be planted directly after collection, thus avoiding problems associated with storage of the cuttings. If cuttings are to be stored, they should be kept moist and at temperatures which minimize respiration (-1° to -4°C). Willow cuttings collected in February were successfully stored in a commercial cold storage unit and used at the end of June, well after the local flora had flushed (Polster, 1992). Cuttings, which are to be stored or transported for any significant distance, should be left in as long pieces as possible. This will minimize moisture loss through cut surfaces. Similarly, small branches and twigs should be trimmed so that the stems can be easily handled. Where a significant number of cuttings are to be collected, it is suggested that the highest quality clippers available be obtained for use as the cost of these will be offset by improved productivity and reduced fatigue.

Cuttings, which are collected from healthy, moderately rapidly growing parent plants, will perform better than those collected from decadent, senescent stems although the tips of stems should be avoided. Marchant and Sherlock (1984) report that cutting material with a low nitrogen / high carbohydrate reserve will root better than "exceptionally vigorous, "sappy" wood...". Where significant amounts of bioengineering work is to be conducted in an area over several years, hedging of parent plants can provide cutting stock. In many cases, local logging sites will provide an abundance of healthy pioneering woody plants, which can be used, for cuttings. Willows, for instance, may be found growing on the side cast side of roadways and on skid trails where mineral soils have been exposed. Powerline, pipeline, railroad and road rights-of-way often provide ideal sites for the collection cuttings as the vegetation in these areas is often maintained in an early serai state. Permission from the landowner must be obtained prior to collecting cuttings from any site. In the case of Crown Land, local Ministry of Forests officers can provide advise on appropriate locations for the collection of cuttings. Care must be taken in the collection of cuttings to avoid environmentally sensitive sites such as stream banks or areas of heavy ungulate use.

Direct planting of root cuttings may be used for the establishment some species. Although the collection and use of root cuttings is significantly more difficult than using stem cuttings, there are cases (e.g. Aspen) where root cuttings provide the best results and stem cuttings are not effective. As with stem cuttings, healthy, moderately rapidly growing roots which are one half to one centimetre in diameter will work best. These should be collected during the dormant period of the parent plant when the parent plant has stored food reserves contained in the roots. Collections should be made well before any flushing of the parent plant in the spring. Collection of root cuttings during clearing operations can provide an efficient means of collecting large quantities of suitable roots. Cuttings should be 5 to 15 cm long and at least 0.25 cm in diameter. Root cuttings must be planted with the proximal end (end towards the parent plant) up, or horizontally. Root cuttings should be planted 2.5 to *7.5* cm deep. As it may be difficult to determine which is the proximal and which is the distal end of a root cutting having one end with a straight cut while the other end is cut on a slant, keeping in mind which is which will assist in determining the proximal and distal ends of the cutting. Root cuttings should be kept moist and planted at the restoration site as soon as weather conditions allow.

BIOENGINEERING SYSTEMS FOR WATER MANAGEMENT

Live Pole Drains

Live pole drains (Figure 1) are constructed of bundles of living cuttings and are used to provide stability to sites where excess soil moisture results in soil instabilities. The bundles of cuttings are placed in shallow trenches in such a manner that they intersect and collect the moisture. The bundles are then lightly buried with local materials, taking care to avoid over-burial. Careful trimming of the cuttings is not required, although the bundles should be as tight as possible. The plants (typically willows) used to form the bundles sprout and grow, with the moisture continuing to drain from the lower end. Sites where excess soil moisture results in site instability can be treated with live pole drains. Traditional engineering solutions often entail the installation of "French drains" or loading the face of the slope with rock. However, live pole drains can be used to drain excess moisture from the site and provide a cover of woody vegetation. The growth from the live pole drains forms the initial cover on the seepage site, allowing other species to invade. As with other bioengineering systems, live pole drains must be designed to suit the specific conditions of the site.

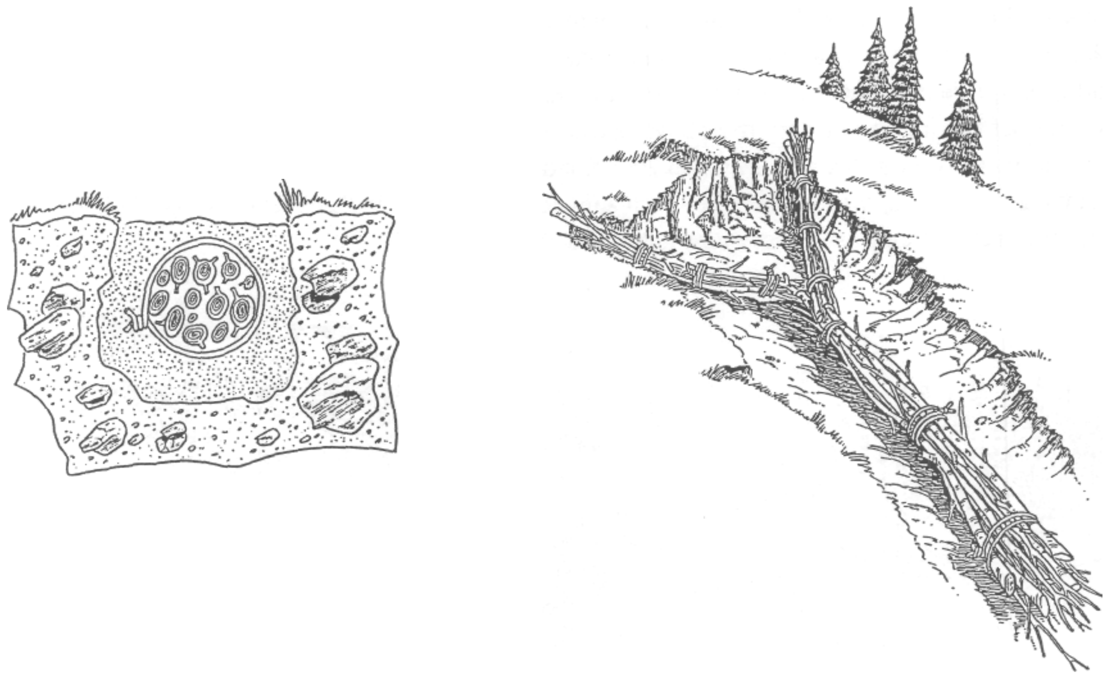

Figure 1. Live pole drains can be used to stabilize slumping soils. This view shows the layout of live pole drains in a slump with the covering soils removed for clarity. The section shows a typical covering. Some twigs from the bundles should be left above ground.

A variety of different shapes can be used for the drains depending on the site conditions. A "Y" pattern of the drains can be used to collect moisture from a diffuse seepage zone while a linear pattern can be used where a discrete seepage site exists. The objective in design of the drains is to collect all of the moisture and to get it to drain away as quickly as possible. The drains grow into a dense stand of hydrophytic vegetation, which is exactly what nature would produce given enough time. Thus this technique fits into the successional reclamation scheme far better than conventional "French" drains would. In addition, live pole drains can be installed without machine access and at fraction of the cost of traditional hard engineering solutions. Soil slumps such as those which occur the first spring after road resloping operations can be stabilized using live pole drains.

Live pole drains are constructed by excavating a shallow trench from the site of seepage down the slope and away from the problem area. A bundle of cuttings is placed in the trench and lightly backfilled with local materials. The bundle is composed of cuttings with tips and butts alternating. The bundle is tied with bailing twine or mechanics wire as tightly as possible. Twigs and branches should be kept on the cuttings where possible as long as this does not result in too loose a bundle. Sites which are particularly wet may require rocks to hold the bundles down in the trench. In these cases, it may not be possible to actually excavate the trench, and the bundles can be inserted by standing on them and pushing them down into the mud. The key to live pole drain construction is to establish the drains in the area of seepage so that the drains provide a controlled alternative for the moisture to escape from the bank.

Live Silt Fences

Live silt fences (Figure 2) are used to reduce sediment movement on low gradient streams. Where live gully blocks 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 smaller streams with lower gradients. The live silt fences are simply rows of cuttings stuck into the streambed to slow water velocities and cause sediments to be deposited. The rows of cuttings also serve to trap floating debris which 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.

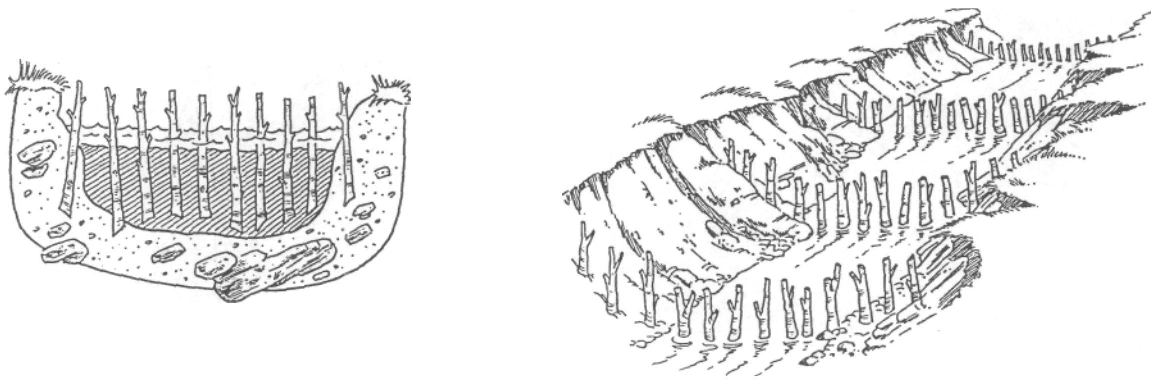

Figure 2. Live silt fences can be used to provide a willow coppice in small streams and ditches. They act by slowing the velocity of the water and allowing sediments to settle out. The cuttings can be either in single rows (as shown) or multiple rows in each band.

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. These will assist in restoring the sites so that 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. Care must be taken to ensure the hydraulic integrity of the drainage system when live silt fences are used.

Live Bank Protection

Live bank protection (Figures 3 and 4) provides a means of stabilizing stream sides which may have become destabilized by debris torrents or through the growth of nick points related to harvesting. Live bank protection can be very useful in stabilizing roadside ditches and culvert inlets and outfalls. By providing living plant materials in these locations, damage which might result from high flows can be avoided and maintenance reduced. Live bank protection structures are wattle fences (see below) built to protect the bank from the scouring action of streams. The typical arrangement for live bank protection provides the 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. The structures are backfilled with local materials, taking care to avoid large cobbles and boulders which will tend to be dry in the summer.

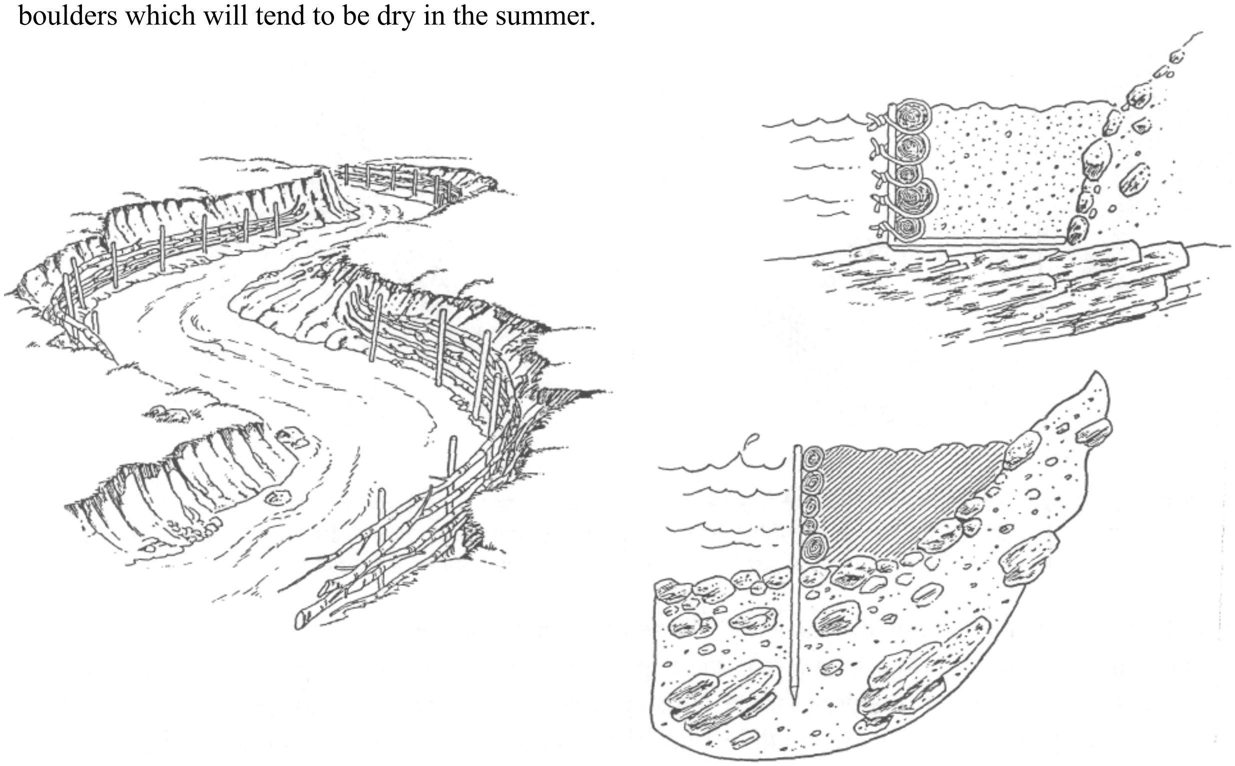

Figure 3. Live bank protection can be used to control erosion on the outside of curves. The backfill has been removed in these drawings for clarity. Typically, the undercut bank would be resloped to backfill be structures. Live bank protection can be used where the stream has eroded the materials down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

Growth of the live bank protection structures provides a cover of riparian vegetation along the streams. The willows and cottonwoods used in the structures provide a strong network of roots which help to hold the stream bank in place. Stabilization of the stream bank reduces the amount of material moving with the water and therefore reduces the erosive power of the water. In addition, live bank protection systems can be used where streams are cutting the toe of steep banks which feed material to the creek. By doing so, the live bank protection systems can reduce the amount of sediment moved from the site and can stabilize the oversteepened bank. Live bank protection systems work best where fine textured soils are being eroded. These can be effectively protected using live bank protection systems.

Live Gully Breaks

Live gully breaks (Figure 4) are large wattle fences (see below) built in gullies to control the initiation of torrenting and the flow of water. Where gully torrents originate from minor collapses of gully sidewalls, live gully breaks can assist in reducing the potential for torrents to initiate. Live gully breaks act by controlling the initiation of torrents rather than attempting to control the torrent once it gets moving. As this is the case, the live gully breaks must be established high in the channel where torrents are initiated. Live gully breaks can be helpful in the revegetation and stabilization of gullies which have already torrented by providing sites where materials may be trapped and where vegetation can become established. As with any bioengineering system, live gully breaks will strengthen with age.

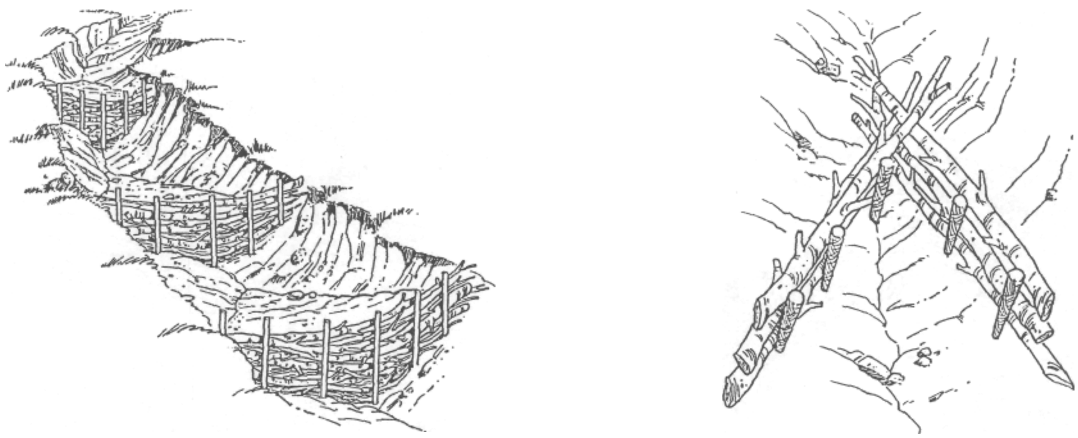

Figure 4. Live gully breaks act to slow the velocity of water movement down a gully and thus to trap sediments. In narrow gullies (right) the cuttings are crossed at the back of the gully (backfill removed for clarity) while in wider gullies (left) the structure is like a wattle fence.

Live gully breaks can be used in ditches and drainages to reduce flow velocities and to provide control of water movement. Working from the bottom, the breaks are established at intervals up the ditch or gully. Spacing of the live gully breaks depends on the steepness of the channel but ranges from 5 to 10 m between the structures. Rebar stakes are driven into the gully to form a crescent on the contour, with the outer ends slightly higher than the stakes near the centreline of the gully. Cuttings (willows should be used) are then established behind the stakes. For tight gullies, the cuttings may need to butt into the opposite side wall, forming an overlapping lattice while on wider gullies, the cuttings may be bent around the inside of the gully. The centre of the live gully break should be lower than the wings to prevent water from flowing out along the wings and creating a problem. The gully breaks may be backfilled with local materials. In some cases, it is useful to provide a rock drain in the centre of the gully break to allow water to flow through, although care must be taken to provide fine textured materials for most of the backfilling. Backfilling should create a small terrace in the gully which will trap additional materials.

Live gully breaks will act to trap materials, which would otherwise serve to initiate a debris torrent or contribute sediment to streams. The physical structure of the live gully breaks will serve this purpose initially while the growth of the cuttings and the establishment of rows of willows will provide long term control of materials. Willows will continue to grow even when deeply buried and will reinforce the soil through the growth of roots. Roots from the willows used in the live gully breaks will provide substantial reinforcement of the soils. Root tensile strengths of birch (expected to be similar to willow) have been measured to be 464 kg/cm^2 for root sizes less than 2 mm while spruce - hemlock roots were found to have a strength of 102 kg/cm^2 for root sizes less than 2 mm. Coastal Douglas fir roots were found to have a tensile strength of 578 kg/cm^2 for root sizes less than 2 mm^2. The root strength of the rapidly growing pioneering species used in bioengineering can replace, in part, that lost due to harvesting activities. Live gully blocks act by creating numerous small structures in the ditches or high on the slopes rather than creating massive engineered structures to trap debris down below. Many bioengineering systems use this strength in numbers concept to create some very stable, strong stabilization systems. Live gully breaks can provide effective control of sediment at or near the source.

Live Staking

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

The cuttings used in live staking 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) so that the top of the cutting will be known when the cutting is planted. The spacing between cuttings will vary depending on the materials, but can be as little as 10 cm. On flowing silts, spacing of about 20 cm work well.

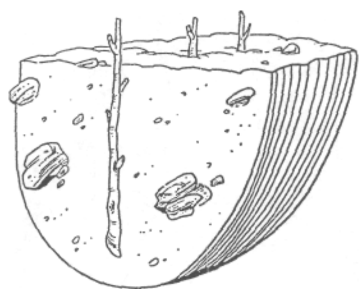

Figure 5. Live staking is a simple method of establishing pioneering woody vegetation. It can be effectively used on "flowing" silts and to establish riparian vegetation along streams.

BIOENGINEERING SYSTEMS FOR STEEP SLOPES

Wattle Fences

Wattle fences (Figure 6) are short retaining walls built of living cuttings. These walls take up the vertical component of the slope, reducing the effective slope angle and allowing vegetation to become established. In addition, the living cuttings used to make the walls sprout and grow, thus further strengthening the structure. Wattle fences are used where site moisture conditions will allow the living cuttings on the face of the fence to sprout and grow. Sites where fine textured soils can provide ample summer moisture or where seepage of groundwater provides moisture are suitable for wattle fence installations.

Wattle fences provide breaks in the slope and can therefore reduce the impact of rolling materials on vegetation growing lower on the slopes. In many cases, vegetation will have difficulty in becoming established where materials from above are constantly bombarding it. Wattle fences can protect vegetation growing lower on the slope and can assist in the revegetation of the sites through protection from rolling rocks and sliding debris.

Wattle fences are used to reduce the effective slope of oversteepened areas. They are most effective where moisture is plentiful and where the cuttings used to construct the fences will not dry out. In this regard, backfilling the fences with fine texture materials will assist in providing moisture during dry summer periods. The first year of fence growth is the most critical as it is at this time that the cuttings may show significant amounts of shoot growth with little supporting root growth. This may cause summer desiccation. Pruning excessive shoot growth can help to balance root to shoot ratios. Willows can continue to grow when buried and therefore provide a good plant material for wattle fences where falling materials are expected to bury vegetation growing lower on the slopes.

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 soupy, the branches and twigs may be retained on the cuttings to provide additional support of the wet soils. Wattle fences can be used in combination with live pole drains (see above) to support the slumps while the live pole drains provide drainage of the excess moisture.

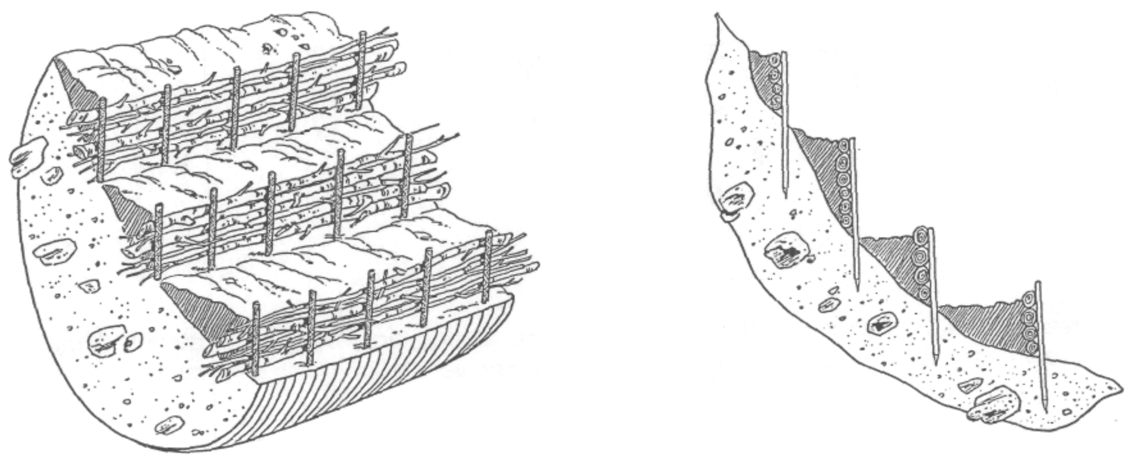

Figure 6. Wattle fences are short retaining walls constructed of living cuttings. They are used to provide slopes, which will support plant growth where oversteepened slopes are preventing plant establishment. The section shows the effects of steeper slopes on wattle fence spacing.

Wattle fences are constructed by establishing the supporting rebar or cuttings in a row in the ground and placing the cuttings behind these supports. Soil materials are then backfilled behind the cuttings and additional cuttings are added with additional backfill to increase the height of the fence. Resloping behind the fence should be conducted to create a slope of about 2 : 1 or less between the top of the fence and the bottom of the fence above. Wattle fences are constructed from the bottom of the slope up the slope so that workers may have a place to stand while additional fences are constructed.

Modified Brush Layers

Modified brush layers (Figure 7) are essentially a brush layer (see below) supported on a short, small log or board. The use of a log for support of the brush layer provides the initial added advantage that the small terrace which is created can serve to "catch" roiling rocks rather than allowing them to roll down the slope, gathering speed and damaging vegetation. Although the log will eventually rot, the cuttings will, by that time, have grown to the point where they are stabilizing the slope. As the cuttings that are used in the brush layer grow, the wall of plants will also serve to trap rocks and soil and prevent movement of materials down the slope, thus further protecting vegetation on the slopes. 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 for stabilization of the slopes.

Logs or boards approximately 2 m in length are used for the modified brush layers. This allows a large number of modified brush layers to be established on the slope rather than one or several long ones. This has the advantage of providing separate, independent structures so that if a very large rock comes down and destroys one of the modified brush layers, there are still others to do the work. Many bioengineering systems use this "strength in numbers" concept.

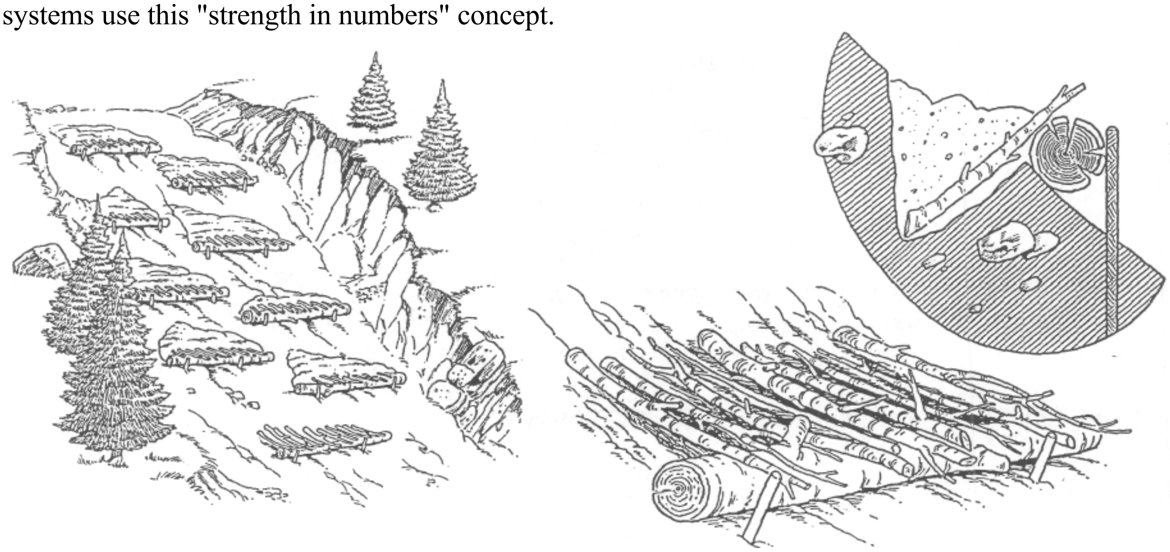

Figure 7. Modified brush layers can be built with either a log or a board for support. They should be staggered across a slope so that material rolling down the slope doesn't have a chance to get going before it is caught. The detail shows a modified brush layer prior to backfilling, while the section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

Reinforcing steel bar (rebar) is used to hold the modified brush layers in place. One hundred and twenty-two centimetre (122 cm) long rebar has been found to be best for support of the modified brush layers. The modified brush layers are constructed by initially establishing the rebar in the ground. The log or board is then placed above the rebar on the slope, and partially back filling behind the log or board creates an initial bench. The cuttings are then placed on the bench and backfill is pulled down to cover the cuttings. The cuttings should stick out past the edge of the log or board about 5 cm. Like wattle fences, modified brush layers should be built from the bottom of the slopes to the tops thus proving places for the workers to stand as they construct additional structures. Modified brush layers can be very useful in the control of ravelling from a road cut slope. The bench created initially serves to trap rolling materials while the growth of the cuttings eventually forms a wall of living plant materials. Modified brush layers can also be effective in the stabilization of sliver fills and ravelling fill slopes.

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 laying in the cuttings. The cuttings should have at least three-quarters of their length in the ground and if the site is dry, seven-eighths of the cuttings should be in the slope. 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. Brush layers in cuts add little to the stability of the cut as no significant bench is created by the brush layer as in a modified brush layer and the cuttings are not deep enough to provide substantial mechanical stability as in brush layer in fill. The wall of plant materials can act to control movement of materials from the slopes and can assist in maintenance of a rod where falling materials are a problem. Modified brush layers (see above) are easier to build and provide more immediate stabilization than brush layers in a cut.

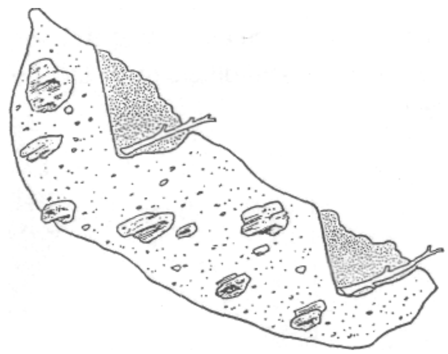

Figure 8. Brush layers in a cut can provide a row of living plant materials and assist in preventing movement of surface materials.

BIOENGINEERING SYSTEMS FOR SOIL REINFORCEMENT

Brush Layers in Fill

Brush layers in fill (Figure 9) are also horizontal rows of cuttings buried in a fill such as a pulled back road. Brush layers in fills are particularly useful where new roads are being built or where roads are being deactivated. In either case, brush layers can be used to strengthen the fill material. 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 (1.5 to 3 in long) can be inserted into the fills as they are constructed and can assist in creating a cohesive mass from the fill material. The cuttings can act like the bands placed in a reinforced earth structure and can give significant mechanical strength to the fill even before they start to grow. As the living cuttings sprout and take root, this strength increases. The development of brush layers in fills may be particularly useful in situations where local oversteepening of the fill is required and incorporation of brush would be useful. Sites such as where gullies cross roads which are being devactivated are candidates for incorporation of brush layers in the pulled back fill. In these cases, the brush layers 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 (see above) may dictate that machine work be organized for these sites at times when cuttings can be used.

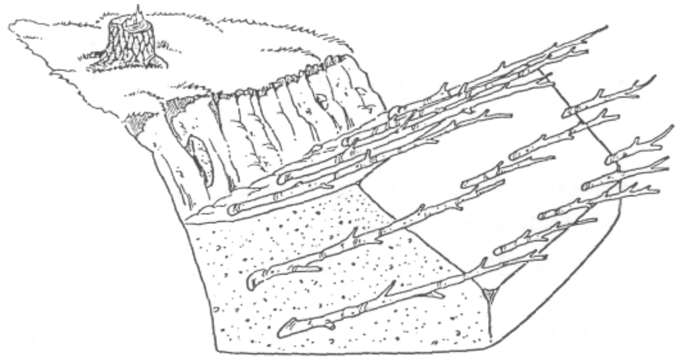

Figure 9. Brush layers in fill can act to reinforce the fill material. Full length cuttings can be used and can be expected to root along their entire length.

Live Staking of Sods

Establishment of a healthy grass and legume cover in cut and fill slopes is a requirement of road construction under the Forest Practices Code. However, in some cases, the cover which is established may tend to "peel" off of the slope. In these cases, live staking (see above) can be used to hold the sod in place and to provide a diversity of rooting depths. This will prevent the development of a slip surface below the sod. The length of the cuttings used in live staking of sods will vary depending on the depth of rooting. However, lengths of 40 to 50 cm should be considered as a minimum. Live staking of sods can provide an effective solution to slipping turf mats.

Conclusions

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

References

Binkley, D., K. Cormack Jr. and R.L. Fredriksen. 1982. Nitrogen Accretion and Availability in some Snowbush Ecosystems. For. Sci. 28(4):720-724.

Gray, D.H. and A.T. Leiser. 1982. Biotechnical Slope Protection and Erosion Control. Van Nostrand Reinhold Company Inc. Scarborough, Ontario, 271 pp.

Hartmann, H.T. and D.E. Rester. 1975. Plant Propagation: Principles and Practices. (3rd ed.) Prentice-Hall Inc. Englewood Cliffs, New Jersey.

Marchant, C. and J. Sherlock. 1984. A Guide to Selection and Propagation of Some Native Woody Species for Land Reclamation in British Columbia. BCMoF. Research Report RR84007-HQ. Victoria, B.C.

Polster, D.F. 1989. Successional reclamation in Western Canada: New light on an old subject. Paper presented at the Canadian Land Reclamation Association and American Society for Surface Mining and Reclamation conference, Calgary, Alberta, August 27-30, 1989.

Polster, D.F. 1991. Natural Vegetation Succession and Sustainable Reclamation, paper presented at the Canadian Land Reclamation Association / B.C. Technical and Research Committee on Reclamation symposium. Kamloops, B.C. June 24 - 28, 1991.

Polster, D.F. 1992. Reclamation of Soil Areas: Alouette Spillway Project, unpublished report prepared for B.C. Hydro and Power Authority. Vancouver, B.C.

Polster, D.F. and M.A.M. Bell. 1980. Vegetation of talus slopes on the Liard Plateau, British Columbia. Phytocoenologia 8(1) 1-12.

Schiechtl, H. M. (Trans. N.K. Horstmann, 1980). Bioengineering for Land Reclamation and Conservation. University of Alberta Press. Edmonton. Alberta. 404 pp.

Straker, J. 1996. Regeneration on Natural Landslides. Paper presented at the Coastal Forest Sites Rehabilitation Workshop. B.C. Forestry Continuing Studies Network. Nanaimo, B.C. October 31 -November 1, 1996.