

# Watershed Restoration Technical Bulletin

## Streamline

Vol. 4 No. 4

## Soil Bioengineering for Steep/Unstable Slopes and Riparian Restoration

David F. Polster

### 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/cm<sup>2</sup> 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/cm<sup>2</sup> and coastal Douglas fir roots were found to have a tensile strength of 578 kg/cm<sup>2</sup>. 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.

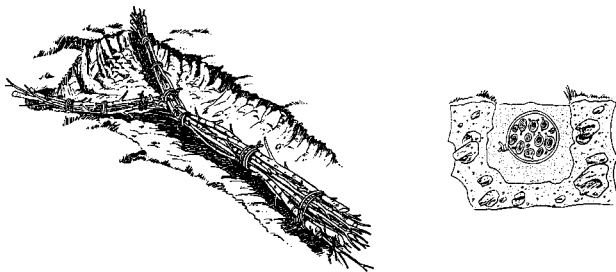


Figure 1. Live pole drains can be used to stabilize slumping soils. This view shows the layout of live pole drains in a slump, with some twigs from the bundles left above ground. The covering soils have been removed for clarity. The section shows a typical covering.

### 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.

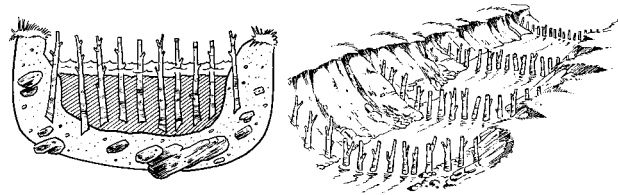


Figure 2. Live silt fences can be used to provide a willow coppice in small streams and ditches. These fences slow the velocity of the water and allow sediments to settle out. In each band, the cuttings can be either in single rows (as shown) or multiple rows.

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.

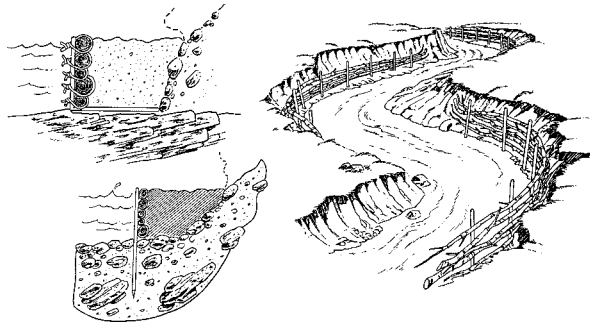


Figure 3. Live bank protection can be used to control erosion on the outside of curves. Typically, the undercut bank would be resloped to backfill the structures. Live bank protection can be used where the stream has eroded the materials down to bedrock or where unconsolidated materials are still present. 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

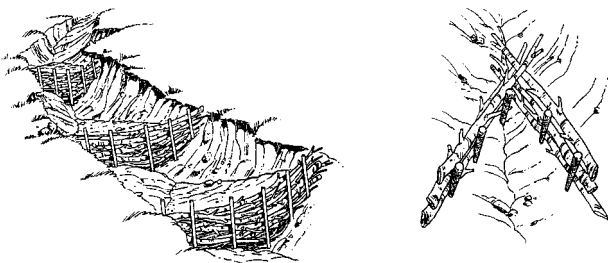


Figure 4. Live gully breaks slow the velocity of water movement down a gully and thus trap sediments. In narrow gullies (right) the cuttings are crossed at the back of the gully while in wider gullies (left) the structure is like a wattle fence. In both cases care must be taken to ensure the water flow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

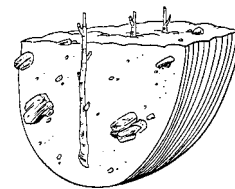


Figure 5. Live staking is a simple method of establishing pioneering woody vegetation. It can be effectively used on “flowing” silts and to establish riparian vegetation along streams.

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.

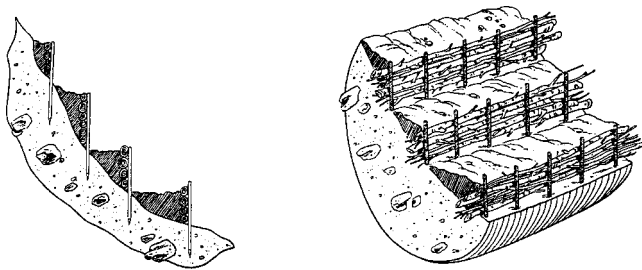


Figure 6. Wattle fences are short retaining walls constructed of living cuttings. They are used to provide slopes, which will support plant growth where oversteepened slopes are preventing plant establishment. The section shows the effects of steeper slopes on wattle fence spacing.

## 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.

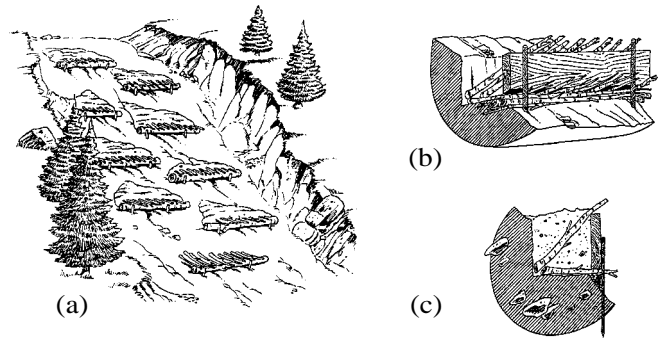


Figure 7. Modified brush layers can be built with either a log or a board for support. They should be staggered across a slope (a) so that material rolling down the slope doesn't have a chance to get going before it is caught. The detail (b) shows a modified brush layer prior to backfilling, while the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

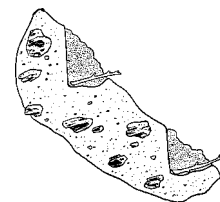


Figure 8. Brush layers in a cut can provide a row of living plant materials and assist in preventing movement of surface materials.

## 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.

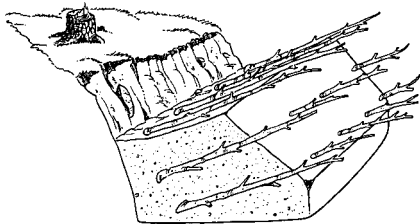


Figure 9. Brush layers in fill can act to reinforce the fill material. Full length cuttings can be used and can be expected to root along their entire length.

## 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).

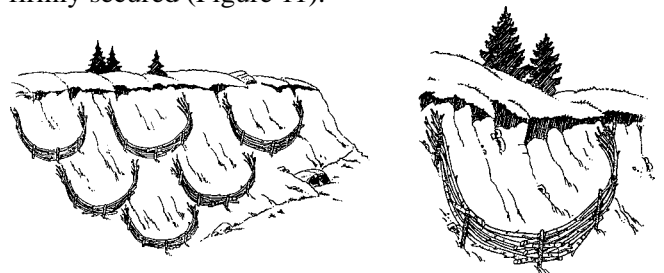


Figure 11. Live smiles have been designed to "suspend" flowing mud on the slope. They use a catenary curve much like a suspension bridge. With good anchors at the top ends, the cuttings are placed in tension. Live smiles are arranged in staggered rows of individual units (left). This uses the "strength 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 m<sup>3</sup> and 8,000 m<sup>3</sup> 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 m<sup>3</sup> of sediment per hectare was collected at this site during the second winter season.

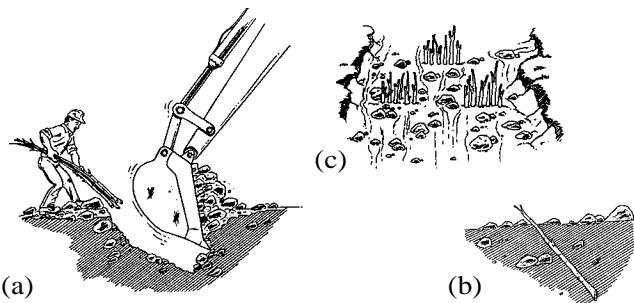


Figure 12. Live gravel bar staking (a) (b) gets the cuttings well down into the gravel bar to reach the water level. Where substrates are coarse, an excavator can be used to get the cuttings into the gravel. This work should be conducted under the supervision of a fisheries biologist. Clumps of live 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

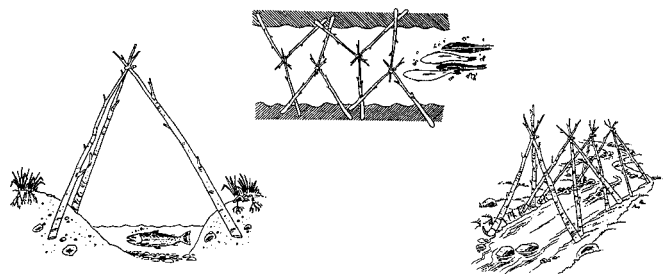


Figure 13. Live shade is designed to provide over-hanging riparian vegetation on newly constructed fish habitat. The structures will send up numerous new shoots while the butt ends of the cuttings will root in the moist soils on the banks. The basal ends of the cuttings used in live shade construction 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.

### 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. Kester. 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. and M.A.M. Bell. 1980. Vegetation of talus slopes on the Liard Plateau, British Columbia. *Phytocoenologia* 8(1) 1-12.
- Schiehtl, 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.

For further information, contact:

**David F. Polster, M. Sc., R.P.Bio.**  
*Polster Environmental Services*  
5953 Deuchars Dr., Duncan B.C. V9L 1L5  
Tel: 250-746-8052; Fax: 250-746-5307  
e-mail: [gsingleton@seaside.net](mailto:gsingleton@seaside.net) ▲

# Hillslope Restoration - Biotechnical Soil Stabilization Demonstration Sites

*Pierre Rossouw and Ernie Carson*

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.

## Contents

### Planning for Watershed Restoration

- Notes from Introduction to Coastal Forest Site Rehabilitation Workshop  
*Roger Stanyer* ..... 1A
- WRP Planning and Priority Setting for the Next Five Years  
*Steve Chatwin* ..... 2A
- Landslide and Roadway Stability Analyses in Timber Industry Watersheds in Northern California  
*Thomas E. Koler* ..... 3A

### Deactivation Lessons Learned

- How Dry is the “Dry Season” on Vancouver Island  
*Allan Chapman* ..... 3A
- Deactivation Lessons Learned on the Wet Side of the Island  
*Glynnis Horel*..... 4A
- Lessons Learned in Coastal Road Deactivation  
*Warren Warttig*..... 4A

### Rehabilitation of Upslope Disturbed Sites

- Long Term Vegetation Development on Bioengineered Sites  
*David F. Polster* ..... 5A
- The Use of Draglines in Road Rehabilitation/ Deactivation: A Case Example from West-Central British Columbia  
*Bruce Dagg* ..... 5A
- Mineral Tenures and Road Deactivation  
*R. Tim Henneberry*..... 6A
- Restoration in Forested Karst Terrain: Planning and Operational Concepts  
*Tim Stokes and Paul Griffiths* ..... 6A
- Forest Site Rehabilitation in Jones Lake Watershed  
*Boris Benko* ..... 7A
- A Storm-based Sediment Budget for Russell Creek  
*Robert Hudson* ..... 8A
- Rates of Revegetation of Gullies in Coastal British Columbia: Implications for Fine-sediment Production  
*Michael J. Bovis and Diane Pellerin*..... 8A
- Effectiveness Monitoring in Road Deactivation  
*Warren Warttig and Mike Wise* ..... 8A

### Risk Management

- Debris Flow Initiation in Coastal British Columbia Gullies  
*Tom Millard* ..... 9A
- Meager Creek Geohazards and Risk Management Study  
*Frank Baumann and Pierre Friele* ..... 10A
- Snow Avalanche Activity in Forested and Harvested Terrain  
*Dr. Dave McClung* ..... 10A

### Fish Habitat Rehabilitation

- Fish and People - Progress in Fisheries Renewal  
*Paul Kariya* ..... 10A
- Fish Habitat Restoration in the Cypre River Watershed  
*John Ebell* ..... 11A
- Off-Channel Spawning Habitat  
*J. Bruce Usher* ..... 11A
- Observations of the Success of the Willow Planting on the Sand, Gravel and Cobble Bars of the Lower San Juan River  
*Gray Switzer* ..... 12A
- Chinukundl Creek Restoration  
*Dave Weir* ..... 12A

## Planning for Watershed Restoration

### Notes from Introduction to Coastal Forest Site Rehabilitation Workshop

*Roger Stanyer*  
Chairman of the Board  
Forest Renewal BC

The Watershed Restoration Program 1998/99 Annual Compendium celebrates the excellent work taking place in the WRP. The Auditor General’s Report of Forest Renewal BC consists of 39 recommendations, of which 30 are underway. The remaining nine would transfer costs to the licensees.

Following the shock of last year's dramatic budget cuts, we have a commitment this year to focus on fish and water, performance, transition, and funding. Meetings with organizations, individuals and community members have helped to prioritize these commitments.

Funding of \$50 million for the current year and the next five years is expected to hold. These funds will be directed to the high priority key watersheds. WRP will continue to focus on whole watersheds, and the approach will be based on impact assessments. The aim is to have Resource Management Plans developed for 2001. Regional workshops are continuing. Tracking Performance and Effectiveness Evaluation are most important in achieving the objectives for the targeted resource values. ▲

## WRP Planning and Priority Setting for the Next Five Years

*Steve Chatwin*  
*Manager of Fish/Forestry and Watershed Research*  
*Ministry of Forests*  
*712 Yates St., Victoria, B.C. V8W 3E7*  
*Tel: 250-387-5887*  
*e-mail: Steve.Chatwin@gems1.gov.bc.ca*

The Watershed Restoration Program has recently established goals of enhancing environmental values by restoring fisheries and aquatic resources in key watersheds throughout the province. The focus over the next five years will be to:

- Emphasize water quality and fish and fish habitat.
- Identify key watersheds in each region.
- Ensure an integrated, whole watershed approach.
- Increase monitoring and evaluation component of the program.

In order to implement Forest Renewal BC's new focus, an interagency team developed Resource Management Plan (RMP) guidelines that will lead to a single RMP for each Forest Renewal BC region. This paper explains how the objectives for the RMPs and investment plans are expected to be achieved.

### **Step 1: Identification of High Priority Key Watersheds**

High Priority Key Watersheds are regionally significant watersheds that contain high values for targeted fish species or domestic water supply, and have a high likelihood of restoration success.

Regional planning teams have largely completed the identification process. For example, Pacific Region

delineated 895 watersheds and targeted 177 key watersheds (20% of the total). The identification process includes the following tasks:

- 1) prioritize fish species by region
- 2) create a base map of watershed planning units
- 3) select watersheds that are important producers or conservation streams for the identified target species
- 4) select important domestic water supply watersheds
- 5) create a ranked list of watersheds (L-VH priority)  
The H and VH watersheds are the Key Watersheds
- 6) categorize the restoration potential for watersheds ranked High and Very High:  
Category 1 – known impacts from pre-Code forestry and high potential for restoration  
Category 2 – significant impacts from other land uses  
Category 3 – minimal impact from forestry related activities  
Category 4 – impacted so severely that restoration is unlikely to be successful  
Category 5 – insufficient data to make a determination

High Priority Key watersheds are all category 1 and 2 watersheds with an inter-agency, coordinated plan in place. The characteristics of these watersheds are:

- ranked H or VH for target fish species or community water supply
- known impacts from pre-Code forest development
- high potential for restoration success

### **Step 2: Selecting Target Watersheds**

This phase is part of the Forest Renewal Investment Planning Process. It involves the selection of Target Watersheds: the High Priority Key Watersheds that will be targeted for restoration activity over the next 5 years. The goal is to restore 20% of the High Priority Key Watersheds over the next 5 years.

### **Step 3: Identifying Sub-Basins and Preparing Restoration Plans**

The next step is the identification of targeted sub-basins within the Target Watersheds, and preparing restoration plans for those sub-basins. The tasks are as follows:

- Within each Target Watershed, identify all of the sub-basins.
- Estimate the impact on fish habitat or water quality by component (hillslopes, riparian, channel) using overview assessment information.
- Estimate the likelihood for restoration success on each component within each sub-basin.

A Restoration Plan for each targeted sub-basin consists of the following:

- Use Level 1 assessments to identify the critical limiting habitat factors for the target fish species and to confirm the priority components for restoration success.
- Prioritize the works within these components based on risk, effectiveness, and cost.

- Schedule the work and the access management.
- The RP sets the benchmark for monitoring and for determining restoration completion.

The goal is that by 2001/02, over 90% of regional WRP investments will be targeted to fisheries and aquatic resource values in priority key watersheds. Some components of the model have already been implemented. A working draft of the guidelines for regional priority setting was incorporated into the 2000/01 Resource Management Plan. Work is now underway to complete the first two phases. A working draft of the watershed level planning guidelines (preparing the Restoration Plan) will be completed by April, 2000. ▲

## Landslide and Roadway Stability Analyses in Timber Industry Watersheds in Northern California

*Thomas E. Koler*  
Staff Engineering Geologist  
Pacific Lumber Company  
Scotia, California

*This paper was presented in Nanaimo by Terry Rollerson, on behalf of Tom Koler.*

Pacific Lumber Company (PALCO) signed a benchmark document on March 1, 1999 with Federal and State wildlife agencies to preserve and protect critical habitat for threatened and endangered species found on the company's timberland. In this Habitat Conservation Plan and Sustainable Yield Plan (HCP/SYP), PALCO management agreed to complete watershed analyses for each of the twenty-two PALCO watersheds by the year 2003.

A natural event in northern California, landslides cause concern for management of industry timber companies in many areas. They affect timber stand health, water quality, and aquatic habitat. Natural occurrences of landslides result from a combination of low shear strength soils, steep hillslopes, high rainfall, and seismic activity. The timber harvesting that has been occurring on PALCO lands for the past 130 years has also been a mechanism for initiating slope movement in many watersheds.

The wildlife agencies stipulated in the HCP/SYP that a modification of the State of Washington Forest Practices Board's Watershed Analysis Methodology be applied in the analyses because the climate and vegetation in northern California is similar to western Washington's. An inter-disciplinary team of watershed scientists was formed in June 1999 to initiate modifications for the various modules. The purpose of this modification was to "fit" the methodology to northern California conditions.

In the modification, the first step is to build a landform map based on topographic expression and geomorphic features. Second, a stratified random sampling of potential landform sites is located on nodes of a 1,000-ft. by 1,000-ft. mesh overlying the landform map. Typically, the number of total samples for a 16,000-acre watershed is 150 to 175. Spatial data are then collected at each site by cross sections, and soil data are collected by soil drive probe, auger, or Standard Penetration Tests. Slope stability is modeled stochastically and a mass-wasting hazard map for each landform type is produced. An overlay of the landslide inventory (completed by time-series aerial photography analysis) is placed for confirmation of observed with predicted data. This landslide inventory is the first step in the Washington State method. It is followed by field verification of the inventory, usually 10 to 20 percent of the inventory, and succeeded by the construction of a hazard potential map. Finally, the road stability is quantified by each landform. For example, self-balanced roadways found on mid-slopes within landform "X" have "Y" risk of delivering sediment to streams from debris landslides, debris flows, or deep-seated landslides.

The mass-wasting module in watershed analysis for the PALCO timberlands is a means for assessing the influence of timber harvest and road activities on resource protection over time. The watershed analysis is a planning tool that is then used for transportation planning and site-specific project analyses. ▲

## Deactivation Lessons Learned

This session was presented by three separate individuals, all of whom have worked on road deactivation projects on Vancouver Island.

### How Dry is the "Dry Season" on Vancouver Island

*Allan Chapman*  
MOF Integrated Resources Section  
1450 Government St., Victoria, B.C. V8W 3E7  
Tel: 250-953-3835

As a result of a rainstorm and landslide that occurred in August near Tranquil Creek in Clayoquot Sound, the question was asked, "How dry is the dry season?" Consensus it seemed to indicate that these storms are pretty rare, but it turns out, upon investigation, that they aren't. Three questions were addressed:

- How common is a 100 mm rainfall in one day in the summer?
- Are there differences in the patterns of summer rainfall across Vancouver Island?
- Are any summer months (May through September) wetter or drier than others?

Data was purchased for the analysis from Environment Canada for a number of climate stations on Vancouver Island. There were 5 sites on the west side of the island and 2 sites on the east side. The sites with one exception were chosen for their long periods of records.

An analysis of the one-day storm rainfall suggests the following:

- short-duration large-magnitude summer rainstorms are common on Vancouver Island;
- the rain magnitudes are large enough to have geomorphic and engineering significance;
- the west side of Vancouver Island appears to be substantially wetter than the east side, with respect to storm rainfall; and
- May, June and July have the lowest frequency of large rainstorms, while August and September have substantially higher frequency. ▲

## Deactivation Lessons Learned on the Wet Side of the Island

*Glynnis Horel*

*Ostapowich Engineering Services Ltd.  
227 Horel Road, Saltspring Island, B.C. V8K 2A4  
Tel: 250-653-4925; Fax: 250-653-4926  
e-mail: oesl@saltspring.com*

As you have just read in the above abstract, there is a large variation in rainfall intensity as you move into the watersheds from the outer coast and there are 100 mm plus events in summer, especially during August. This causes landslides to occur. In addition, both “minor sediment redistributions” in new deactivation and debris flows form open slopes, gullies and old roads. These facts imply the following:

- Access planning is required, particularly drainage management.
- There is increased risk until the deactivation is completed.
- Worker safety requires that rainfall shutdown criteria be implemented.
- Silvicultural work should be coordinated with deactivation work.
- Time is of the essence, even fairly early in the season.

Try to plan for speed in deactivation methodology by:

- Advance planning of project logistics
- Selection of equipment type and size

- Ensuring operator experience
- Planning extra shifts during long daylight and weekends in favourable weather
- Using excavators working in tandem where feasible

Working in Tandem has the following advantages:

- It is an advantage on wide roads, deep fills and gullies
- Can provide training opportunities – radio communication between machines
- Safety
- Speed
- Travel time minimized

Inspections are the single most significant factor in achieving expected standard of work. Forest Renewal BC projects do require sign-off of completed work and we have learned that it is important to have on-site review prior to start up, and frequent inspections at the early stages of work to establish the expectations of performance. The person that is expected to sign off on the work must be involved especially at the early stages. In addition, this individual must have adequate opportunity to inspect work in progress. This person may work with an experienced senior inspector who thoroughly understands the prescription and prescriber’s intent.

The inspection reports will contain details on “as-built” against the prescription. Inspectors will note where work is satisfactory, as well as noting any deficiencies. There should be notes as to any additional work that is to be done and re-inspected, whether erosion/stability hazards remain as a result of the deficiency, and what is the consequence. If “monitor” sites are identified, clearly indicate what type of monitoring is to be done, and what, if any subsequent action would be expected from outcomes of the monitoring. A clear conclusion should be stated as to whether or not the work meets the intent of the prescription. In general, if there were inadequate inspection opportunities for the person signing off, you are more likely to get a deficiency report without clear acceptance of the work. ▲

## Lessons Learned in Coastal Road Deactivation

*Warren Warttig*

*Interfor, Kingcome Enhanced Forestry Division,  
Box 31 – 2960 Spit Road,  
Campbell River, B.C. V9W 4Z9  
Tel: 250-286-4547 loc.254  
e-mail: Warren\_Warttig@Interfor.com*

Road deactivation has evolved significantly over the last eight years. With the advent of Forest Renewal BC, the amount of deactivation occurring throughout BC increased dramatically. In many cases, to meet this increased demand, a “cookie cutter” approach was

used for deactivation. This approach resulted in the over-prescribing of some roads, and the under-prescribing of others. As well, it often failed to incorporate changing techniques for effective hill-slope stabilization, or increased emphasis on risk management (rather than hazard management).

Over-prescribing low-risk roads resulted in unnecessary loss of access, while the under-prescribing of high-risk roads failed to meet stability concerns. In some cases, the reactivation of previously deactivated roads is required, in order to re-deactivate to the required standard. To meet specific objectives, each road must be assessed separately, with prescriptions developed based on risk and future access. Effectiveness monitoring is also recommended to ensure that prescriptions and road deactivation techniques are meeting site-specific and project objectives. ▲

## Rehabilitation of Upslope Disturbed Sites

### Long Term Vegetation Development on Bioengineered Sites

*David F. Polster, M.Sc. R.P.Bio.  
Polster Environmental Services,  
5953 Deuchars Drive, Duncan, B.C. V9L 1L5  
Tel: 250-746-8052; Fax: 250-746-5307  
e-mail: gsingleton@seaside.net*

Soil bioengineering is the use of living plant materials to construct an engineered structure or to perform an engineering function. Bioengineering is used to treat steep and/or unstable slopes. Wattle fences are short retaining walls built of living cuttings that have been widely used to treat steep slopes. Wet seepage areas can be treated with live pole drains, and modified brush layers can be used on raveling slopes to control the movement of surface materials. In all of these cases, the soil bioengineering structures are used to address some form of instability that is preventing natural plant establishment and growth. Once the initial instability is overcome, subsequent plant establishment can proceed.

This paper explores the processes of site stabilization and plant establishment on sites where soil bioengineering was used for initial stabilization. Key elements encouraging natural successional processes are presented in the context of these sites. Projections are made about the future of sites where new soil bioengineering techniques have been applied. Examples are drawn from the author's experience. ▲

### The Use of Draglines in Road Rehabilitation/Deactivation: A Case Example from West-Central British Columbia

*Bruce Dagg  
Jacques Whitford and Associates,  
#1-3771 North Fraser Way,  
Burnaby, B.C. V5J 5G5  
Tel: 604-436-3014; Fax: 604-436-3752  
e-mail: bdagg@jacqueswhitford.com*

In August and September 1998, Skeena Cellulose Inc. (SCI) undertook a major project to stabilize sections of three active logging road corridors in the West Kitsuns area south of Hazelton, B.C. Slide activity along or below these roads had damaged fish habitat in Kitsuns Creek and its tributaries, and also presented a safety hazard along some sections of the roads. Cutslope instability was also a problem in some areas. Because the roads were still required for future timber harvesting, permanent deactivation and re-contouring of unstable areas was not a suitable option.

Several different slope stabilization measures were used on this project, including:

- pullback of excess sidecast fill immediately below the roads using excavators working from the roads;
- construction of temporary tote roads to enable removal of excess sidecast material beyond the reach of excavators on the roads; construction of rock buttresses and toe berms to support the road or the toe of the road cut;
- installation of subsurface seepage collection/interception measures, surface water diversions, and hydroseeding and/or planting exposed slopes with cottonwood (live staking).

We used one measure which, to our knowledge, has not been widely employed in this application in British Columbia. This was the use of draglines to remove excess fill well below the road, in areas where the construction of tote roads was considered impractical or unsafe. This enabled significantly more material to be recovered at some of the sites than would have otherwise been possible. Problems included the greater width of road required for the machine to swing, and difficulties with stumps and logs embedded in the fill.

Jacques Whitford and Associates (JWA) and SCI completed site investigation and engineering design for this project, with input from the Ministry of Forests, Prince Rupert Region. JWA provided field supervision and ongoing consultation during construction, assisted by Skeena Project Services Ltd. (SPS). Funding was provided by Forest Renewal B.C.

The author thanks Tim Dunne, P.Eng. of Chiltech

Forestry Ltd. (formerly with SCI), Howard DeBeck, P.Eng., of the Ministry of Forests, Lorne Sexton of SPS, and Armando Abello Jr. of JWA for their input and assistance with this presentation. ▲

## Mineral Tenures and Road Deactivation

**R. Tim Henneberry, P.Geo.**  
*Mammoth Geological Ltd.*

604 Noowick Road, R.R.#1, Mill Bay, B.C. V0R 2P0  
Tel/Fax: 250-743-8228  
e-mail: mammoth@cow-net.com

The purpose of the talk was to explain in simple terms the need for road access for mineral exploration and to demonstrate how to obtain mineral tenure information for any watershed in the province. These are very broad subjects, therefore two key aspects of mineral tenures and road deactivations were covered:

1. Mineral exploration impacts in coastal watersheds
2. Identifying active mineral tenures in a specific watershed.

A requirement of all watershed deactivation proposals is to obtain information on active mineral tenures within the watershed. Most of this information can be readily obtained from the Ministry of Energy and Mines web site. This, and the mapping process, was also described in detail.

Editor's Note: This information will be included as the Tech Tip in Vol.5, No.1 (June 2000). ▲

## Restoration in Forested Karst Terrain: Planning and Operational Concepts.

**Tim Stokes**

*Terra Firma Geoscience Services,*  
1480 Sherwood Dr., Nanaimo, B.C. V9T 1G7  
Tel: 250-754-2476  
e-mail: tstokes@island.net

**Paul Griffiths**

*Cave Management Services,*  
544 Springbok Road, Campbell River, BC, V9W 8A2  
Tel: 250-923-1311 Fax: 250-923-6211  
e-mail: pgriff@island.net

Past watershed restoration projects in British Columbia have in many cases overlooked the significance of karst terrain. This distinct landscape requires a specific approach to restoration. Approximately 5-10% of B.C.'s land mass is underlain by soluble bedrock types (e.g., limestone, dolomite, marble) that can potentially develop karst. Productive coastal and interior forests overlie a significant proportion of these potential karst

areas. Karst terrain can be considered a three-dimensional system with its own geomorphology, hydrology and biological characteristics. The main distinguishing characteristics of karst terrain are: a lack of surface drainage, an irregular surface topography, and a subsurface network of conduits.

The primary objectives of karst management are to preserve karst ecosystem and to ensure that natural, dynamic karst processes are not unduly modified. A secondary objective is to provide opportunities for persons to engage in scientific research, appropriate recreation, and educational pursuits. While recognizing the non-renewable nature of many karst features, particularly in caves, good management demands that damaged features be restored insofar as this is practicable.

Karst rehabilitation must be based on sound principles of geology, hydrology, meteorology and biology. Geologically, natural rates of sedimentation, weathering, and erosion should be restored so that the natural quality of the karst resource is maintained, with protection of any vulnerable geological features (e.g., cave sediment or sub-fossil sites). For karst hydrology, catchments and flow regimes should be restored to a near-natural state, along with restoration of normal rates of surface run-off, infiltration, and subsurface flow. Where possible, introduced debris materials should be removed from water courses so as not to cause further damage. Air quality and movement in karst biospaces should be returned to as nearly natural a state as possible by removing any physical obstructions and polluting sources. Finally, biological resources of the karst site should be restored to their natural state as far as possible.

Karst restoration requires both careful assessment and planning prior to any field activities. In general, restoration of karst sites is probably more effective and worthwhile where evidence for past forestry activities is readily apparent. Restoration of very old sites, where some level of natural recovery has occurred, may be less beneficial and in some cases possibly detrimental. Karst restoration projects require accurate delineation of the site, careful assessment of hydrological, meteorological, geological and biological functions, and the identification of sensitive features. The project objectives should be well defined, and any practical constraints identified. All karst restoration methods should be carefully designed with scheduling, contingency and monitoring plans in place.

Restoration can be applied to both the surface and underground components of karst. Examples of surface restoration activities include the following:

- Restoration of natural soil-vegetation systems in sensitive epikarst zones (e.g., appropriately revegetating areas prone to soil piping and/or loss).
- Employing special tree planting techniques (e.g., planting seedlings in soil-filled solution openings).

- Replacing non-native plant species with perennial native species (depending on the nature, extent and impact of non-native species on the karst site).
- Restoration of karst sites formerly used for ballast quarrying, waste storage, or disposal.
- Restoration of karst sites modified by roads and landings (e.g., where infiltration is impeded by impervious road or landing surfaces).
- Controlling the erosion along sinking streams (in both carbonate and contributory non-carbonate uplands).
- Controlling erosion on destabilized sideslopes within linear and point karstic depression features.
- Removing unnatural accumulations of debris from sink points.
- Eliminating or designing drainage control structures that unnaturally divert surface water flows and recontouring sealed road surfaces to shed water laterally.
- Deconstructing roads to restore 'inaccessibility' to sensitive karst features.
- Installing sinking stream filters upstream of sink point (e.g., grizzly, screen, cloth) to reduce ongoing impact.
- Recovering windthrown trees from sensitive features.
- Reviewing the need for all existing roads within the karst catchment.
- Relocate access roads outside sensitive karst sites and their catchment, if possible.

Examples of subsurface restoration activities, following careful assessment, can include:

- declogging subsurface caves and conduits, and
- high-pressure washing of rock surfaces (e.g., silt films, stains, needles)

Rehabilitation of a karst site should not be done without a sound and complete understanding of the surface and subsurface components of the karst system. This knowledge can be drawn from karst inventory and assessment information. Three levels of karst inventory have been proposed to better identify and evaluate the karst landscape. These inventories have been developed mainly with active forest development (e.g., harvesting and road construction) in mind, however they can also be applied to restoration projects.

The highest, or reconnaissance, level at 1:250,000 scale has been completed for BC with the development of a set of preliminary karst potential maps. This inventory is an office-based analysis of regional bedrock data and is intended only to identify and flag likely areas of karst development. For any restoration project, these maps can quickly be consulted to determine whether the area of interest or watershed occurs within a likely karst area.

The planning level inventory, typically at the 1:20,000 scale, uses field work to delineate the boundaries and

three-dimensional shape of the karst unit, determine the intensity and variability of karst development, and evaluate the regional hydrology. This information could be critical to a watershed restoration project in terms of prioritization, identifying sensitive areas (e.g., failing road fill slopes above a series of swallets or cave entrances) and its overall effectiveness (e.g., leaving roads with minimal surface runoff and identifying streams leading into swallets where debris cleaning is required).

The operational level inventory at the 1:5,000 or 1:10,000 scales evaluates in detail the karst system at a site, assessing the types and distribution of surface karst features, as well as their connection to the subsurface. At this inventory level, karst features can be identified and evaluated for their significance with specific prescriptions determined for restoration (e.g., removal of logging debris from an important sinkhole or sinking stream). Old roads and quarries can be also assessed for deactivation at this level, and prescriptions determined to minimize the impact on karst hydrology and its associated surface and subsurface features. ▲

## Forest Site Rehabilitation in Jones Lake Watershed

**Boris Benko**

*P. Machibroda Engineering Ltd.,  
44325 Yale Rd. W., Chilliwack, B.C. V2P 6H7*

The slopes above the eastern shore of Jones Lake, a BC Hydro reservoir, (in the Skagit Range of the Cascade Mountains) have experienced significant disturbances by forestry road-related landslides. The area has significant socio-economic values with public interests including a BC Hydro reservoir (Jones/Wahleach Lake built in 1951-52), fisheries resources, two campgrounds, cabins, a drinking water supply for the cabins, and an active mainline logging road. The detailed investigation used an array of geological, geotechnical, geomorphological and bio-engineering techniques. With the exception of bio-engineering, the project was completed in four months. The final aspect of the project, the bio-engineering, was scheduled for completion in November 1999.

The roads were deactivated following prescriptions provided by a multidisciplinary team of professionals including geoscientists, geotechnical engineers and bio-engineering specialists. Deactivation prescriptions ranged from water management structures excavated by hand-held tools to a complete removal of road fill in the most critical areas and recontouring of the slope. Landslide rehabilitation concentrated on minimizing further instability in the headscarp areas and minimizing

the erosion and sediment transport from landslide tracks. Gully rehabilitation was confined to areas with the highest likelihood of future instability. The objective of the site rehabilitation, with respect to the existing water supply system for the Jones Lake cabins, was two-fold: to prevent sedimentation of the water source and to improve the water supply system by constructing a subsurface intake. ▲

## A Storm-based Sediment Budget for Russell Creek

*Robert Hudson, P.Geo., Ph.D.  
Research Hydrologist  
Vancouver Forest Region  
Tel: 250-751-7114*

A sediment budget investigation was carried out in Russell Creek watershed to determine the relative contribution of different types of sediment sources to the sediment load of mainstem channel sites in Russell Creek and its main tributary, Stephanie Creek. The investigation was a success. Its findings were that the sediment yield measured in the creeks was very similar in volume to the total sediment production at those main sediment sources that are connected to the channel network. Overall, sediment contribution from sources affected by logging amounts to 20% of the total sediment yield. There is no evidence to suggest that logging has increased sediment yield from gullies or landslides. The biggest sediment producers are naturally occurring sediment sources. Sediment contributed by road-related sources amounts to 15% of the total sediment yield. The sediment yield at road crossings is directly proportional to the area of exposed sediment on cut-and-fill slopes that has not been stabilized by deactivation or rehabilitation. ▲

## Rates of Revegetation of Gullies in Coastal British Columbia: Implications for Fine-sediment Production

*Michael J. Bovis and Diane Pellerin  
Geography Department,  
University of British Columbia  
217-1984 West Mall  
Vancouver, B.C. V6T 1Z2*

Large tracts of forested terrain in coastal British Columbia are dissected by gullies. Because of their steepness and instability, they are important sources of sediment and large woody debris. Much of this material is delivered by debris flows, triggered by relatively

small debris slides on steep, unstable gully walls. Following a debris flow event, large quantities of fine sediment are produced as a result of the scouring of gully sidewalls. Scouring is usually deep enough to strip the gully sidewalls of most of the vegetation cover. This exposes large areas of bare soil to accelerated erosion by rainsplash, overland flow, dry ravel, and frost heave. This cycle of accelerated sediment production persists for several years after a debris flow, but relatively little is known about the time frame of gully sidewall destabilization and the associated decline in sediment production.

The main objectives of this study have been to compare the rates of recovery of gully revegetation between logged and unlogged areas, to estimate the fine sediment discharge from gully sidewalls at different stages of vegetation recovery, and to examine the role of abiotic factors such as slope angle, aspect, soil conditions, and moisture regime on plant succession and fine sediment production. A total of 92 vegetation quadrats in 15 gullies in Coquitlam basin were surveyed on gully sidewalls, and eighteen of the 92 plots were monitored for one year with sediment traps 1.2 m in width.

In the first five years following debris flow scour, average sediment yields from logged gully sidewalls were greater than double those from unlogged sidewalls. Over a 15 - 20 year period following debris flow, sediment yields in both environments declined, but at a slightly higher rate on logged sidewalls. This is associated with more rapid growth of fast colonizer species, which cause sharp reductions in bare soil area over time. ▲

## Effectiveness Monitoring in Road Deactivation

*Warren Warttig and Mike Wise  
International Forest Products  
Box 49114 Vancouver, B.C. V7X 1H7  
Tel: 250-751-7199; Fax: 250-751-7190*

Road deactivation is the "deconstruction" of forest roads to accomplish three typical project objectives: decrease slope instability, minimize erosion, and enhance site productivity. Deactivation is commonly carried out as part of Watershed Restoration Projects (WRP) sponsored by Forest Renewal B.C. (FRBC). Road deactivation is also carried out as part of regular operations in forest development, as required by the Forest Practices Code.

This report documents the effectiveness of road deactivation work to accomplish these typical project objectives. Field indicators of potential instability, potential erosion, and existing forest site productivity were used as a means of determining whether the work

carried out to deactivate the road met the objectives. Due to the close link between the site level objectives (road deactivation prescriptions) and the project level objectives, more elaborate consideration of the component level (intermediate) objectives are not necessary to determine the effectiveness of road deactivation.

The effectiveness monitoring reported in this study is for the Lost Shoe-Thunderous Creek and Toquart Bay areas on western Vancouver Island. Eleven sites were evaluated with respect to common visual field indicators of potential instability and erosion. Observed revegetation at the sites within two circular plots was recorded, and the data compiled to qualitatively evaluate the revegetation at the sites. For the eleven sites, the road deactivation work was successful in decreasing slope instability and minimizing erosion due to the absence of field indicators at all but three sites. Statistical analysis of the plot data revealed that most sites had a good cover of grass with abundant alder growth. Conifer regeneration was more sporadic, due to damage by deer and perhaps inadequate soil sorting during pullback.

Recommendations are provided for continued monitoring of these study sites and future effectiveness monitoring projects. These involve using local and project-specific experience to select the study sites, in conjunction with senior personnel familiar with road deactivation techniques and monitoring studies. Where possible, the site evaluation procedure should be made as straightforward as possible, using simple visual indicators where appropriate. A photographic record should be kept for the study sites, to provide a visual record of the site over time. ▲

## Risk Management

### Debris Flow Initiation in Coastal British Columbia Gullies

*Tom Millard*

*Ministry of Forests, Vancouver Region  
2100 Labieux Rd., Nanaimo, B.C. V9T 6E9  
Tel: 250-751-7115*

This study investigates debris flow initiation hazard in Coastal British Columbia gullies. A total of 286 slope failures were analyzed, of which 75 were debris flows. Four geographic areas were field assessed: north of Nitinat Lake on Vancouver Island, south of Nitinat Lake, the Squamish River and Mamquam River drainages in the Coast Mountains, and the Deena Creek and Ghost Creek drainages in the Queen Charlotte

Islands. The study involved collection of information on gully and slope failure characteristics, including slope failure location (headwall or sidewall), gully wall slope angle, gully wall slope distance, channel gradient, surficial material and surficial material depth, soil drainage, slope failure dimensions, the volume of slope failure debris delivered to the channel, the planimetric angle of entry of the slope mass into the channel, and whether the slope failure continued to transport as a debris flow down the gully channel.

Slope failures in gully headwalls were much more likely to initiate a debris flow than slope failures in gully sidewall locations. Headwall debris flows initiated on lower gradient slopes than sidewall debris flows. The minimum initial failure volume required to initiate a headwall debris flow was about half the volume required to initiate a sidewall debris flow (11 m<sup>3</sup> compared to 25 m<sup>3</sup>). Angle of entry is closely associated with location. The median headwall slope failure angle of entry is 0°, compared to the median sidewall slope failure angle of entry of 74°.

In addition to gully location (headwall or sidewall), the initial failure volume and the volume of debris delivered to the channel were the most important factors in determining whether a slope failure would result in a debris flow. Larger initial failures, and larger amounts of debris delivered to the channel, were much more likely to initiate debris flows than small slope failure volumes. Larger volume slope failures are associated with deeper surficial materials on sidewalls, but not headwalls. Surficial material depth, or terrain type, divided into shallow and deeper classes, is significant in the prediction models. About 90% of debris flows had at least 80% of the initial failure volume delivered to the gully channel.

Although three of the geographic areas (South Nitinat, Squamish, and Queen Charlotte Islands) did not have significant differences in debris flow initiation, the fourth area, North Nitinat, showed a different pattern. The most likely explanation for this difference was the presence of highly sheared bedrock within gullied areas.

The results of this study showed that debris flow initiation is a complex process. As with most geomorphic processes, a significant degree of uncertainty exists. The results of this study better define the factors which are associated with debris flow initiation. However, there are limitations to this type of study, therefore caution must be used when applying these results. Terrain scientists should examine relationships between local slope failures and debris flows in gullies before applying these results to specific locations in Coastal British Columbia. ▲



## Meager Creek Geohazards and Risk Management Study

*Frank Baumann and Pierre Friele*  
Box 1846, Squamish, B.C. V0N 3G0

Meager Creek Hotsprings has been a popular wilderness destination for at least 75 years. However, since the documentation of a major landslide that occurred in 1931, it also has been recognized as one of the most geologically active areas in Canada.

Starting in the early 1970's, when logging roads allowed easy access to the valley, recreational use increased dramatically. This eventually led to overuse, and ultimately, to a temporary closure of the area in 1996 for health reasons. During this time, there were also a number of additional landslides that destroyed or damaged hundreds of thousands of dollars worth of equipment and structures, stranded numerous people and their cars, and, tragically, killed a number of BC Hydro workers who were exploring for geothermal energy. There have been hundreds of additional events, involving both large and small quantities of rock, debris, water, or snow.

Following the occurrence of a major debris flow in 1984, the Ministry of Forests, Squamish District became involved in attempting to define and manage the landslide hazard in the Hotsprings Creek Recreation Area. This work resulted in the delineation of specific camping and day-use only areas, increased signage, and re-alignment of the South Meager FSR to prevent the road from capturing Hotsprings Creek and directing it into the hotsprings area. Additional major debris flows in 1987 and 1990 illustrated the on-going nature of the activity and risk in this area.

In 1998, after resolution of the health problems, re-development of the site started, partially funded by Forest Renewal BC. However, in July 1998, a 150 m section of the access road to the hotsprings was destroyed by an estimated one million cubic metre debris flow which came down Capricorn Creek, and blocked Meager Creek. It then formed a new, one kilometre long lake behind the debris dam. This major event was followed in the spring and summer of 1999 by innumerable additional events that continually blocked the road and stranded visitors and forest workers in the valley. These events triggered a re-assessment of proposed development plans in the Meager Creek Hotsprings Recreation Area. It also led to the commissioning of a major geohazards study that is attempting to define all hazards in the area and establish their run-out areas and potential impacts. A second important objective of this study is to provide specific information on risk management and development options so that land managers can ultimately define

levels of acceptable risk for various activities, and then decide where, and under what restrictions, those activities can take place in the Meager Creek area. ▲

## Snow Avalanche Activity in Forested and Harvested Terrain

*Dr Dave McClung*  
NSERC-FRBC-CMH Chair in Snow and Avalanche Science  
Department of Geography  
1984 West Mall  
University of British Columbia  
Vancouver, B.C. V6T 1Z2  
Tel: (604)-822-9157; Fax: (604)-822-6150  
e-mail: mcclung@geog.ubc.ca  
<http://www.geog.ubc.ca/avalanche>

Snow avalanches have affected at least 10,000 clear-cuts in British Columbia. An overview of the problem based on our research was presented. Our study sites include an area in the southern coast range and an area in the interior, each with about 500 examples. The summary is a progress of work to date toward risk-based decision methods and inclusion of guidelines in the Forest Practices Code. The goals of the project are to provide:

- modelling of magnitude and frequency of avalanches in clear cuts
- magnitude, frequency and dynamics of avalanches in forested terrain; and
- decision support for logging in steep alpine terrain. ▲

## Fish Habitat Rehabilitation

### Fish and People – Progress in Fisheries Renewal

*Paul Kariya,*  
Fisheries Renewal BC  
405 - 960 Quayside Dr.  
New Westminster, B.C. V3M 6G2  
Tel: 604-660-0939; Fax: 604-660-0931

Most of us cannot believe that in the span of less than a decade, the economic and social character of fisheries in British Columbia have changed so drastically. While wild fish are still being caught, some stocks are facing extreme difficulty. With the advent of salmon farming, the market place for B.C. wild salmon has

changed radically. Communities dependent upon fishing have gone through a tremendous upheaval. Despite all these changes, the message to British Columbians and the world is that fisheries in this hold a bright future.

Established by provincial legislation in 1997, Fisheries Renewal BC is one of the province's newest Crown corporations with a mandate to help restore habitat, protect fish, and encourage fish production. The corporation is also charged with assisting in diversification, opening up new fisheries, new product development, job creation, and assisting fish-dependent communities.

To date there has been a balance of inputs in restoration and enhancement. The focus of the Fisheries Renewal funding is directed to community-based models, local decision-making, and broad-based partnerships.

We need examples of new fisheries and numbers from habitat improvement. There is encouraging news from new fisheries such as neon squid, mackerel, tilapia and crayfish. ▲

## Fish habitat Restoration in the Cypre River Watershed

**John Ebell**

*J. A. Taylor and Associates Ltd.  
1483 Outrigger, Nanoose Bay, B.C. V9P 9B6  
Tel: 250-468-1437  
e-mail: jebell@island.net*

In 1996, with funding from FRBC, MacMillan Bloedel catalyzed the formation of a partnership for fish habitat restoration in the Cypre River. The participants are Weyerhaeuser Canada Ltd., Nuuchahnulth Tribal Council, Ahousaht First Nation, Tofino Enhancement Society, Provincial Forest Renewal BC and Fisheries Renewal BC, as well as the Federal Department of Fisheries and Oceans. This collective has contributed support, technical expertise, equipment, and most important, multi-source funding.

The Cypre River is located approximately 15 km northeast of Tofino in the coastal temperate rainforest of Clayoquot Sound, on the West Coast of Vancouver Island. The watershed drains an area of approximately 60 km<sup>2</sup>. Historic logging practices in conjunction with poor slope stability have affected the channel morphology. Observable changes typically involve increased bedload and associated aggradation in low gradient sections of the river.

Overview and instream assessments indicate a lack of high water juvenile refuge habitat as being one of the primary limits to fish production. The lack of stable spawning substrate throughout the lower reach was

also noted as a significant concern.

The highest instream restoration priority focused on the loss of protected winter refuge habitat. In 1998, the first restoration project was completed: a groundwater-fed coho rearing channel located 9 kilometers upstream. Monitoring has shown this new habitat to be highly utilized. During the summer of 1999, a second off-channel project was built primarily to provide stable chum salmon spawning habitat. The secondary objective was to create overwintering and refuge habitat for coho and other salmonids. A trial was also undertaken in 1999 to test the function of low-profile conifer brush bundles as mainstem cover structures. The effectiveness of this year's projects is not yet fully known.

The habitat restoration projects in the Cypre River watershed have had positive social impacts. So far, more than 25 individuals have been employed at a wide range of tasks to accomplish the work. Almost all of these have been local residents. This activity has nurtured community "ownership" for a previously remote and relatively under-monitored resource. The momentum of this partnership and its activity is planned to continue. ▲

## Off-Channel Spawning Habitat

**J. Bruce Usher**

*Watershed Restoration Technician,  
Chilliwack Forest District  
PO Box 159 9880 S. McGrath Rd., Rosedale, B.C. VOX 1X0  
Tel: 794-2241; Fax: 794-2111  
e-mail: Bruce.Usher@gems3.gov.bc.ca*

Why do we do off-channel fish habitat restoration work? Off-channel habitat has been lost due to stream channelization, dyking, and forest road construction. These areas provide a stable, clean water supply and over-wintering rearing habitat for local populations of fish. They also function as refuge for immigrant fish moving out of main channels during high flows. Off-channel ponds and streams trap nutrients, most of which is in the form of returning salmon carcasses.

Once established, the returning salmon provide a food source for fish, birds and mammals. Upland or riparian vegetation also benefits. Constructing off-channel streams and ponds is a quick and cost-effective way to reestablish fish and wildlife abundance and to strengthen genetic variability of fish populations.

These sites also provide an effective forum for public education. Controlled flow off-channel ponds and streams, whether groundwater- or surface-fed, are designed to renew ecological links and to restore fish and wildlife abundance back to historical levels and/or

to compensate for permanently lost habitat by using natural templates as guides.

The reasons we do off channel work are to:

- restore habitat for fish and wildlife, and
- control the flow and water quality (choosing the right site) to provide stability over time.

Target species for off channel work are:

- ground water channels/infiltration-Chums/Coho/steelhead;
- surface water channels-Steelhead/Coho/Pink/Sockeye/Chums/Chinook. ▲

## Observations of the Success of the Willow Planting on the Sand, Gravel and Cobble Bars of the Lower San Juan River

*Gray Switzer*

*Duncan Forest District*

*5785 Duncan St., Duncan, B.C. V9L 5G2*

*Tel: 250-746-2777*

*e-mail: Gray.Switzer@gems1.gov.bc.ca*

In the spring of 1998 and 1999, an extensive willow planting of the migrating sand, gravel, and cobble bars of the lower San Juan River was undertaken. The intent of the program, the underlying reclamation principles, the implementation logistics, and observations of the performance of the work, as well as a discussion of current success were presented in an interim report.

The project shows that planting techniques have a valuable role in stabilizing damaged channels. Observations suggest that willow plantings benefit from using larger, deeper placed stock that better survives the natural and anthropogenic rigors of this environment. Large diameter machine-planted willows showed superior growth. Survival rates following the summer drought showed that the deeply buried willows fared better than the ones that were not as well dug in; most survived the heavy browse and mechanical damage by 4X4s. The fall floods provided the most interesting results, with large quantities of sediment being deposited on the plantations. Sediment deposition and river scour combined to create a more defined riverbank and thalweg. The paper summarizes the specific techniques, performance and logistics issues associated with the success of the project.

It is apparent to the author that vegetative techniques are worthwhile. They can help produce stable river morphologies when applied to disturbed river sites, by improving channel performance and enhancing in-stream habitat.

The San Juan River Watershed Restoration Project is funded by Forest Renewal BC, involving TimberWest

(now TFL Forests Ltd.), the Ministry of Forests South Island Forest District Duncan office, the Pacheedaht First Nations, local forest workers group, the local fish hatchery, various contract specialists, and with the co-operation of Ministry of Environment, Lands and Parks, DFO and the San Juan Steering Committee. ▲

## Chinukundl Creek Restoration

*Dave Weir*

*Engineering Officer, Queen Charlotte Forest District*

*Tel: 250-559-6213 Fax: 250-559-8342*

*e-mail: Dave.Weir@Gems3.gov.bc.ca*

Chinukundl Creek is a high value fish stream located on the south-east side of Graham Island in the Queen Charlottes. In 1992, a 90 hectare block located on an escarpment above the lower end of Chinukundl Creek was harvested by Fletcher Challenge. Since then, a number of landslides have directly affected Chinukundl Creek. Numerous waterbars and X-ditches failed to reduce landslide frequency. Attempts to disperse water had met with limited success.

In 1997, an interagency committee consisting of members from the Ministry of Forests, the Department of Fisheries and Oceans, TimberWest Limited, and the Hecate Straight Stream Keepers, was formed with the objective of rehabilitating both the up-slope and the in-stream areas of Chinukundl Creek. Professional assistance was contracted to do the assessment. Funding was approved in July 1998, subject to money being spent prior to April 1999. Projects were divided into up-slope and back channel works. The committee decided to attempt to divert water away from the areas of instability. Upslope, trench upgrades were conducted under the direct supervision of a registered professional. Slide areas that could be accessed safely were hand-seeded and fertilized. Great care was exercised to preserve standing vegetation and, where necessary with the instream work, rip-rapping was completed by hand. Water is now controlled through a supply pond with a check dam. The purpose was to create sediment-free over-wintering habitat.

The actual costs were \$129,954. The cost of the Level 1 Assessment was \$26,065. The trench upgrade was \$6115, professional design for new trench construction was \$30,072 and the professional supervision of construction was \$20,954. These costs do not include district and regional support costs. The initial estimate for surface water interception is approximately 65%.

Monitoring continues; however, funds are limited. Success or failure cannot be determined at this stage, and only time will tell what impact these trenches will have on landslide size and frequency. ▲



Figure 1. The location of the Kingfisher Creek and Cooke Creek demonstration sites.

Secondary failure of the sidewalls of the transport zone occurred again in 1998. Biotechnical soil stabilization techniques in the form of modified brush layers, wattle fences, and live pole drains were installed in the fall of 1997. The sidewalls of the transport zone were treated with wattle fences in the fall of 1998. Because the site is wet, biotechnical soil stabilization techniques have been fairly successful in spite of a very dry summer in 1998.

One aspect of the work completed at this particular demonstration site bears mention: the selection of fall rather than the spring work windows at this location. For some time, the best work window for restoration work has been the subject of vigorous debate amongst practitioners of biotechnical soil stabilization techniques. Most agree that the spring work window (using cuttings collected in the winter) produces the best results. Unfortunately, landslide-prone terrain such as the site at 4km is unpredictable during the breakup period. Crews working in these areas during the spring may be exposed to an unacceptable level of risk. Therefore, it is to our advantage to consider both fall and spring work windows, here, and in landslide-prone terrain.

The second demonstration site involved restoration of a cutslope in raveling sand. This site was treated with modified brushlayers in the fall of 1997. The very dry summer of 1998 resulted in failure of 80% of the cuttings planted in 1997. Monitoring of the site during this hot, dry summer revealed that cottonwood cuttings were more robust than willow in dry conditions. In addition, thicker cuttings survived longer than thinner cuttings taken from second year growth. This site was replanted in the fall of 1998. The summer of 1999 was wet and the site is now relatively well established.

Shading and establishment of leaf mould on top of the sand should aid in arresting the drying and raveling of the sand. Under these conditions, it is likely that conifers will eventually populate the site, so that over time its condition will be similar to that of the surrounding forest.

The third demonstration site was a deeply incised gully formed by ditch water flow off a switchback on the Cooke Creek FSR at 1.7 km. The ditchline above the switchback carries water for some 400 meters to flow out onto unstable, 60% slopes. The result has been the formation of a deep gully in the unstable till material of the slope. The sidewalls of the gully have become unstable, and on the adjacent hillslope are extensive tension cracks, associated with a loss of toe support at the gully. The most obvious solution in a case such as this is the introduction of cross culverts above the switchback to lessen flow and lead ditch water onto the flatter terrain below this part of the road. Unfortunately, cross culverts on this section of road would discharge ditch water directly above private property. As this could cause damage to the private property, forest road managers have not been able to install culverts in this section of road.

The tension cracks and other obvious signs of instability and eminent failure in the gully led to the decision to proceed with treatment of the gully before additional culverts could be introduced, and without lessening of the flow. This deeply incised gully is approximately 6 meters deep with steep sidewalls. Restoration objectives in this instance were to arrest down-cutting and loss of toe support, and to treat the sidewalls. To achieve these objectives, wattle fences were constructed on the sidewalls. These have a 2% fall to the center of the gully, and were configured in the form of "arrow heads." In this treatment, the wattle fences meet in the center of the gully forming appropriate gully breaks to dissipate energy and to arrest down-cutting (Figure 2). Work at this site was undertaken in the fall of 1998. Because the site is fairly wet, there has been vigorous growth and the treatment is successful at this stage.

Acting as lead proponent for restoration work in the Brash Creek Watershed, Spallumcheen Band has subsequently had success using the "arrow head" configuration of wattle fences in a similar circumstance. Brash Creek is a community watershed a few tributaries to the South of Cooke Creek.

The MOF and MELP are presently developing interpretive signs and a brochure to illustrate demonstration values and the locality of sites for both the instream and hillslope components in Kingfisher

# Feature



Figure 2. Gully treatment at Cooke Creek FSR 1.7 km. The wattle fences were configured in the form of “arrow heads” to dissipate energy and arrest downcutting.

and Cooke Creeks. This interpretive work has been undertaken in partnerships with Spallumcheen Band and the Kingfisher Interpretive Center (a community-based educational institution). The aim is to fully realize the instructional value of the extensive demonstration work in these watersheds.

## Hints and Tips

1. Choose work season according to potential risk at site.
2. Cottonwood cuttings have a better survival rate than willow cuttings in well-drained, drier situations.
3. When constructing wattle fences, additional benefit can be gained by tying horizontal cuttings at 90° to the fence, into the slope. This can be done as the layers of the fence are being constructed. Leave the end of these cuttings sticking out of the fence by 50 mm to 100 mm.



Figure 3. Specialized rebar pounding tool made out of pipe and bars.

4. 20M rebar is far more effective than 15M.
5. A specialized rebar pounding tool can be made out of pipe and bars (Figure 3). With proper design, the pounding of rebar for wattle fences and modified brush layers can be made significantly easier. (Editor's Note: WRP courses are now suggesting the use of wooden stakes (sapling stakes) instead of rebar because rebar is not biodegradable

and will not contribute to vegetative growth as stake post/pole sapling cuttings will. Rebar should only be considered if extremely hard soils are encountered.)

6. Use cedar planks (5/8" x 8") for modified brush layers (Figure 4). Individual cedar planks are: (i) easily transported in bundles on site; (ii) light and rot-resistant; and (iii) easily cut with a hand saw, eliminating the need for chain saws and all the regulations associated with their use.



Figure 4. At this site, cedar planks were successfully utilized in modified brush layers.

7. Live pole drains work best when the tops of the bundles are partially exposed.
8. Wattle fences at the toe of the escarpment will catch some of the raveling wall, but may fail or be covered if too much raveling takes place.
9. Leave non-danger trees on the margins of the slide. Such trees are a potential seed source for the successional growth of conifers on the slide. In addition, if they do fall into the slide area they provide a natural stabilizing effect and can bring organic matter down onto the rehabilitating slope (Figure 5).
10. With proper, controlled application of fertilizers, accelerated grass/legume growth can occur. This also assists in the establishment and growth of cuttings.



Figure 5. Non-danger trees remain on the margins of the slide providing a seed source. If they do fall into the slide area they can provide a stabilizing effect and bring additional organic matter onto the slope.

11. In particular cases, wattle fences can be tied back using heavy gauge wire and rebar stakes. This adds to the vertical stability of the wattle fence.
12. “Weaving” of the wattle fences has a benefit over tying only.

For further information, contact:

**Pierre Rossouw**

*PO Box 100, Salmon Arm, B.C. V1E 4S4.  
Tel: (250) 833-3400, Fax: (250) 833-3399  
e-mail: Pierre.Rossouw@gems2.gov.bc.ca*

**Ernie Carson**

*WRP Engineer, Ministry of Forests  
Kamloops Forest Region  
515 Columbia Street, Kamloops, B.C. V2C 2T7  
Tel. (250) 828-4133 Fax (250) 828-4154  
e-mail ernie.carson@gems6.gov.bc.ca* ▲

## Seeding for Site Rehabilitation

*David C. Sahlstrom*

The Forest Practices Code (FPC) requires the seeding of disturbed forest areas to prevent impacts from erosion, and this has become a common procedure during watershed rehabilitation as well. Although the benefits of seeding are well documented, a thorough understanding of the science is required to realize these benefits consistently. There are three primary benefits to seeding – erosion control, soil development, and site revegetation or rehabilitation. These three benefits have common components and some aspects of one may limit the benefits of another.

Seeding should always include a mixture of both grasses and legumes. The grass component can include either native species, agronomic species and cultivars, or both. The legume component can include a variety of species from the legume (or pea) family. All legume species have flowers that are similar in shape to the pea flower (although the flowers on some species are so small their similarity may not be noticeable without a magnifying glass). They include clovers, alfalfa, birdsfoot trefoil, lupines, and sainfoin, among others.

### **Erosion Control**

Vegetation is the most effective means of controlling erosion and it protects the environment from the negative impacts of sediment transport and deposition. Grasses and legumes can provide a strong mat that

protects the soil surface from erosion caused by precipitation, flowing water and wind. It is possible to use other types of vegetation for erosion control but seeding with grasses and legumes has proven to be very effective in most situations. Initial erosion control during seed germination and establishment can be provided through the use of mulches, tackifiers, erosion control revegetation mats, and other surface protection measures. However, a strong contiguous mat of vegetation provides longer-term erosion control. Research has shown that a cover of 70 to 80% will effectively control erosion and 65% cover is considered a minimum for erosion control (Bergland 1976, Homoky 1996, Sahlstrom 1997).

### **Soil Development**

The role of grasses and legumes in soil development may be the most overlooked aspect of site rehabilitation but it has significant impacts on future success of replanting and reforestation attempts. A healthy, vigorous cover of grasses and legumes can transform barren, infertile subsoils into productive topsoils in an amazingly short time. Under natural grassland conditions, topsoil development has been estimated as requiring 500 years for every 2.5 cm. The establishment and maintenance of a grass and legume cover can accelerate this process and significant contribution to topsoil

# Feature

development can be seen in less than five years. Organic matter contribution from the grasses and legumes can be as high as 1600 kg/ha per year.

The contribution to soil development of grasses and legumes depends on the types of species seeded, and their growth rates. Legumes (such as clover, birdsfoot trefoil, alfalfa, etc.) are very important for their ability to fix atmospheric nitrogen. Legumes in forest plantations can provide from 35 to 200 kg/ha of fixed nitrogen annually (Binkley 1986). For example, one five-year study showed that legume growth increased the nitrogen pool by 890 kg/ha on a coastal soil and by 332 kg/ha in the interior (Carr 1987). One of the significant benefits is that the majority of fixed nitrogen is in the form of organic nitrogen that is not readily leachable. In comparison, alders fix nitrogen at a rate between 27-320 kg/ha per year in pure stands with the majority of studies reporting results of less than 100 kg/ha per year. Mixed stands of alders and conifers fix less than this (Hibbs 1994). One of the benefits of using legumes over alders for soil improvement is the opportunity it provides to replant forest seedlings into the legume cover with limited competition.

## Revegetation and Acceleration of Natural Rehabilitation

Site rehabilitation is an integrated process involving soil, vegetation and water. In natural rehabilitation, a pioneering vegetation cover generally develops, stabilizing the site. These pioneering plants improve the soil fertility and increase the soil organic matter. With time, shrubs may colonize the disturbed site, further improving the soil fertility and providing an environment in which trees can establish. Typically, this natural succession may take years, decades or even longer to occur.

The establishment of grasses and legumes on disturbed sites can provide initial revegetation and initiates the rehabilitation process. Although rehabilitation of disturbed sites will be accomplished naturally given enough time, the process can be accelerated using grasses and legumes that provide a combination of beneficial effects. Erosion control by the grasses and legumes provides a stable site for germination and establishment of native species. Seed availability is improved as the plants intercept wind-blown seed. They also intercept wind-blown microbes, fungi spores, etc.; these are necessary for site rehabilitation and create an environment suitable for the germination and establishment of other species.

It is important to carefully consider the role of the seeded grasses and legumes in the long-term vegetation cover. In naturally forested areas, the seeded species

are temporary and will be replaced through natural succession by trees and shrubs. Seeded species may persist much longer in grasslands, possibly preventing native species from becoming established.

Plant growth and persistence are a result of the interaction of plant species, seeding technique, site conditions and maintenance. It is simplistic to predict performance based on plant groupings such as bunchgrass versus sod forming grasses. In some conditions, aggressive sod formers such as creeping red fescue may perform like bunchgrasses and some bunchgrasses may develop a solid cover that out-competes all other species. Such is the case with *Calamagrostis canadensis*, which is a bunchgrass that is so aggressive in the Peace River area that successful reforestation depends on controlling it (Watson 1980). In the dry interior the seeding of another bunchgrass, crested wheatgrass, has proved successful for range improvement, and has displaced complete native communities without any maintenance.

A long-term study has shown that seeding with grasses and legumes accelerated the rehabilitation of hydroseeded road cuts and fills. The long-term (up to 10 years) role of the grasses and legumes differed according to the biogeoclimatic zone and site conditions. In some areas the seeded vegetation became a sub-story to a thick canopy of brush and trees. In other areas, although the seeded cover was predominant, native shrubs and trees were establishing throughout. Although all seventeen sites were seeded with a seed mixture that included aggressive sod forming grasses such as redtop (*Agrostis alba*) and creeping red fescue (*Festuca rubra*), the seeded vegetation cover did not prevent the invasion and establishment of native species (Homoky 1987).

Maintenance prescriptions also affect plant performance. Seeded grasses in infertile sites will be stunted and may even die off without adequate maintenance fertilization. Perennial Ryegrass, (a perennial bunchgrass) is used extensively for site rehabilitation as it germinates and establishes rapidly. It is generally regarded as a short-lived, non-aggressive species that dies out over about five years. However, it is also used extensively in the turf industry where, under intensive management practices, it forms long-lived, tight-knit sod required for golf courses and playing fields.

Seeding does not result in a vegetation cover that remains static – even in well-maintained, aggressive covers. Rather, the cover adapts, matures and moves through succession stages during the succeeding years. Initially, pioneering species may account for the majority of the mixture, whereas the slower developing

species may not be noticeable. If included in the seed mixture, fall rye may appear to be almost the only species growing in the first year; at this early stage the project might appear to be a failure, with the fall rye consuming the available nutrients and out-competing the slower-growing species. However, in the second year, the fall rye will be dead leaving behind a well-established cover of perennial grasses and legumes.

An appropriately designed project will provide a seed mixture, application technique, and maintenance requirements that consider the short and long-term objectives for seeding and the effect of site conditions on meeting those objectives.

### Competition

Most of the available research on grass and legume competition has been focused on plantations with topsoil horizons. There are relatively few studies that examine competition on disturbed soils and even fewer (if any) that approach the subject from a rigorous scientific perspective in examining the impacts and interactions of seed species, fertilization, soil development together with short and long-term seedling survival and growth. However, disturbed sites without fertile topsoil are not capable of supporting conifers. There must be some form of soil rehabilitation and development prior to establishing a conifer plantation and a cover of grasses and legumes can provide this.

Studies on plantation performance provide little evidence that seeding grasses and legumes decreases tree seedling survival except on dry sites where moisture deficit has a significant impact on seedling survival. It has been postulated that using larger planting stock may offset this effect. In addition, seeding grasses and legumes has been shown to provide effective control of shrubby weeds such as fireweed and thimbleberry, thereby actually improving seedling performance (Drinkwater 1994). On the other hand, competition by native grasses, forbs and shrubs is a problem and there has been significant research into methods of control (Harper 1998).

In many cases, the development of a healthy cover of grasses and legumes may benefit and improve tree growth. Figure 1, a photograph taken on northern Vancouver Island, depicts healthy vigorous trees growing on a road fill that has a heavy cover of grasses and legumes. These trees were larger, fuller, and healthier than those trees in the adjacent plantation.

### Seed mixtures

Site rehabilitation requires a seed mixture that accomplishes the objectives for rehabilitation. It must germinate and establish quickly (often in inclement



Figure 1. Planted Douglas Firs are thriving in a road fill slope that has a heavy cover of grasses and legumes. The trees are benefiting from the improved soil conditions provided by the grasses and legumes.

weather and varied soil and climate conditions) to control surface erosion as quickly as possible. It must also assist in building topsoil through biomass production, decomposition and humus generation. The vegetation must encourage the invasion of successional forbs, shrubs and trees but persist until the successional vegetation is adequately developed to replace the planted cover. In general, this requires a seed mixture comprised of multiple grass and legume species.

### Species selection

Species selection must consider management objectives for the vegetation cover over both the short-term as well as the long-term. If a long-term objective is to restock the area, species selection criteria should focus on erosion control and soil building. If the mixture is expected to persist and form the long-term cover, persistence and native status should be part of the selection criteria.

The selection should also consider species adaptability to site conditions such as soil type, fertility, erodibility, moisture content and water-holding capacity. Localized variability in site conditions may require a variety of species that are adapted to different site conditions. For instance, although the site may be in a high rainfall area, localized drought conditions may exist in sandy soils that have low water holding capacities.

Germination and growth habit of the different species affect the resulting vegetation cover. Some species may produce small plants while others may be very large. In addition, some plants may spread and grow larger through successive years and develop into the dominant species. In the first year, birdsfoot trefoil (a legume) remains very small plant, usually with a

# Feature

single stem less than 8 cm high. It may take two or three years for it to develop into a noticeable plant, and after five years it may be a dominant specie. For this reason, its important contribution to site rehabilitation has often been discounted as a result of seed mixture evaluations that rely on short-term results.

## *Mixture Design*

As discussed above, seed mixture design is a complex procedure based on scientific principles. It must take into account:

- management objectives,
- site conditions,
- germination and growth habit of the species,
- planting method and season, and
- future climate conditions and site response.

Currently, there is considerable disagreement among professionals regarding appropriate seed mixtures. Much of the disagreement results from a failure to consider the objectives and benefits derived from seeding. If the primary objective is to control erosion and the climax vegetation is a dense forest cover, then short-term aggressive grasses and legumes should be selected for the mixture. Many “native” species would not be suitable, as they are slow to germinate and establish. If the soil is an infertile glacial till and the objective is to return it to a forest eventually, the mixture should include soil building species. Seed houses are great sources of information for seed characteristics.

When designing seed mixtures, one should start with the objectives and then determine the appropriate species to achieve those objectives. Seed mixtures can then be developed that will provide the desired vegetation cover. It is generally accepted that the species distribution in the seed mixture should mirror the desired vegetation cover, but this reflects only one of the factors that influence the eventual vegetation composition. Weather, seeding methodology and season, soil moisture, soil characteristics, and seed-bed conditions all affect germination and establishment. For example, since clovers prefer moist sites with fine textured soils but do poorly on dry coarse soils, the same clover-containing seed mixture would produce different results on dry sites than on moist sites. Figure 2 is a photograph that shows a site at which two test plots were installed using different seeding methodologies but the same seed mixture. The near plot was broadcast seeded and has a very poor vegetation cover. Many of the species in the seed mixture are not present in the vegetation cover. The far plot was hydro-seeded with a heavy application of mulch. As can be seen, the vegetation cover is heavier, and has a greater species diversity.



Figure 2. The plot in the foreground was dry broadcast, whereas the plot in the background was hydro-seeded with a heavy mulch application using the same seed mixture and fertilizer. Note that the hydro-seeded plot has a healthier vegetation cover with a greater species diversity.

## *Pure Live Seed*

Although species percentages are generally expressed on a weight basis, the percentage by Pure Live Seed (PLS) is more important. Pure Live Seed is the product of mixture percentage, seed weight, purity and germination percentage. Seed weight is generally expressed as seeds per kilogram and each species or cultivar has a nominal seed weight. For example, redtop has about 11.0 million seeds/kg while creeping red fescue has about 1.3 million seeds/kg and perennial ryegrass 0.5 million seeds/kg. The seed weight can vary as a result of varieties and plant vigor so precise seed counts are probably not valid. Purity and germination percentages are determined for each seed lot that is harvested and by law they must meet specified minimums to meet regulated grades. Note that, although reject seed lots are sometimes used in seed mixtures used for forest rehabilitation, this is not recommended as they may contain prohibited weed species.

Using Pure Live Seed targets, percentage by weight can be determined for the seed mixture. Some judgement should be used with respect to the level of precision in specifying the seed mixture. Adjusting species content by even as much as ten percent of the species seed count has little effect on the resulting vegetation cover. Specifying percentages to the nearest percent is more than adequate – specifying tenths of a percent is overkill.

## **Seeding Methodologies**

There are three primary methodologies for seeding – drill seeding, dry broadcast seeding, and hydroseeding.

### *Drill Seeding*

Drill seeding places the seed under the soil surface and

is the primary method used in farming. Drill seeding requires soil and site conditions that allow a seed drill to plant the seed, which is very rare in the forest environment. Seed application rates for drill seeding are very low relative to other seeding techniques.

#### *Dry Broadcast Seeding*

Dry broadcast seeding is probably the most common method for seeding disturbed forestland. The seed may be broadcast by hand, using a cyclone spreader, or with equipment. Helicopters and airplanes can be used for seeding large, inaccessible areas. As the dry broadcast method provides no surface or seed protection, it is only applicable for slopes less than 1:3 where erosion is not a concern. In general, the vegetation cover is slow to develop when it is broadcast seeded: it may be delayed by two years, as compared to a site that is hydro-seeded. If soil development and site rehabilitation are important objectives, broadcast seeding may not produce the desired results.

#### *Hydroseeding*

Hydroseeding is the application of seed using a water slurry which may contain fertilizer, mulch, tackifier, soil amendments, or other ingredients. Hydroseeding requires the use of equipment specifically designed to constantly agitate and pump the slurry without damaging the seed. A properly designed and applied hydroseeding application can provide surface protection and control erosion on slopes steeper than 1:3.

The inclusion of additives such as mulch and tackifier in the slurry promotes rapid seed germination and establishment and will result in a heavier, more vigorous vegetation cover with greater species diversity. One of the recommendations from a study on mulch effectiveness conducted by the Ontario Ministry of Transportation was that mulches should be applied at rates greater than 1600 kg/ha (Alder 1988). Application of mulch at rates less than 1000 kg/ha is not adequate to control erosion and provides little mulching effect.

#### **Fertilization and refertilization**

In addition to developing an appropriate seed mixture and application methodology to achieve the defined objectives, the vegetation cover must be fertilized and maintained. Typically, the disturbed sites are void of nutrients required for plant growth, so these are generally provided in chemical form during the seeding and establishment. As the vegetation cover grows, it converts the chemical fertilizer to organic matter that must undergo decomposition and mineralization before it is available for plant uptake. Regular refertilization of infertile sites is required to maintain an adequate cover for erosion control and soil development. If the nutrients are not provided, the

cover will decline, soil development will be hindered, and site rehabilitation will be retarded.

As the site progresses through the rehabilitation phases and topsoil once again is present, the requirement for a healthy vigorous cover of legumes and grasses diminishes. The maintenance of this cover therefore can be reduced, allowing native vegetation to become established on the site. This often occurs within five to eight years of the initial seeding. By this time, the nutrient pool has become large enough to support growth without further inputs and the site could be restocked with commercial species.

#### **Final Comments**

Rehabilitation of disturbed sites is a process that may take years to accomplish. The process should begin with a detailed assessment of site conditions and the development of specific objectives. Without clear objectives, the rehabilitation program will have a lack of focus and there will be no criteria for selecting appropriate rehabilitation methodologies or evaluating their success. Consequently, a multi-year program that provides for monitoring and maintenance is usually required.

An effective rehabilitation program should attempt to accelerate the natural rehabilitation process through the use of selected plant species, fertilizers and planting programs. Each step in this natural process from initial seeding through establishment of seral and climax plant communities must be adequately addressed to ensure successful results. A blanket approach that does not consider the varied conditions of different sites will result in projects that do not achieve their full potential.

#### **References**

- Alder, V. and P. Prier, 1988. Hydraulic mulch application rates for control of soil erosion. Ministry of Transportation of Ontario. Downsview, Ontario. 60pp.
- Bergland, E.R. 1976. Seeding to control erosion along forest roads. O.S.U. Extension Service, Corvallis, Oregon. 19pp.
- Carr, W.W., 1980. Handbook for forest roadside surface erosion control in British Columbia. BC Ministry of Forests research contract E.P. 834. Victoria. 43pp.
- Carr, W.W., 1987. Restoring productivity on degraded forest soils: two case studies. FRR002. BC Ministry of Forests. Victoria. 36pp.
- Drinkwater, Bob. 1994. Agroforestry trials in the Prince Rupert Forest Region: in Grasses and legumes in forestry. FCS Network. 89pp.
- Harper, G.J., P.G. Comeau, B.S. Riring, W.J. Reid, P. Fielder. 1998. A comparison of mulch mat and

# Update

herbicide treatments for reducing grass competition in the IDFww. Extension Note 27. BC Ministry of Forest Research Program. Victoria.

Hibbs, David E., Dean S. DeBell, and Rober F. Tarrant. 1994. The biology and management of red alder. Oregon State University Press.

For further information, contact:

**David Sahlstrom**  
Terrasol Environmental Consulting  
3-33557 Maclure Road, Abbotsford, BC  
Tel. 604-852-3782 ▲

## Conferences

**Watershed 2000 Conference** is being held at the Hotel Vancouver, Vancouver, B.C. July 9-12, 2000. It is being held by the Water Environment Federation in cooperation with the BC Water and Wastes Association. It is specifically designed for: biologists, civil and environmental engineers, consultants, educators, environmentalists, equipment manufacturers and suppliers, government officials, hydrologists, lawmakers, public works officials, regulators, soil and erosion control specialists, wastewater managers, water suppliers, and wetland research scientists. If you are interested, then visit WEF's WEB Site: <http://www.wef.org>. The agenda was not available at press time, but should be soon.

**The 62<sup>nd</sup> Midwest Fish and Wildlife Conference** takes place Dec. 3 – 6 in merry old Minneapolis. The call is now out for papers.

## Workshops

**Coast Silviculture Committee Summer Workshop.** June 21 and 22 at the Coast Discovery Inn, Campbell River, B.C. The theme is "Variable Retention Harvesting." For further information, contact Tom.Hedekar@ mala.bc.ca.

**2000 Coastal Forest Site Rehabilitation Workshop** will be Dec. 6 – 8 in Nanaimo. More information to follow in the next Streamline.

## Websites

For all watershed restoration personnel, the following websites are well worth bookmarking:

WRP: [www.env.gov.bc.ca/fsh/wrp/index.html](http://www.env.gov.bc.ca/fsh/wrp/index.html)

MOF: [www.for.gov.bc.ca/](http://www.for.gov.bc.ca/)

MELP: [www.env.gov.bc.ca](http://www.env.gov.bc.ca)

FRBC: [www.forestrenewal.bc.ca](http://www.forestrenewal.bc.ca)

FRMB: [www.elp.gov.bc.ca/frco/frphome.html](http://www.elp.gov.bc.ca/frco/frphome.html)

## Perspectives

**Wanted:** your perspective on various controversies in the field of "watershed restoration." For example, is it worthwhile to selectively stabilize bars in streams? This column has been suggested by Streamline readers, and we encourage you to contribute your ideas. Your perspective should be in the range of 500 words (a short dialogue). Please send your perspective to Donna Underhill at [dbuirinc@axion.net](mailto:dbuirinc@axion.net), or fax it to 604-224-6880. If preferred, a mailing address is provided in the next column.



## Streamline

Published and Produced by:  
**Watershed Restoration Program**

B.C. Ministry of Environment,  
2204 Main Mall, Vancouver, B.C.  
V6T 1Z4 Fax: 604-660-1849

Editor: Donna Underhill  
Fax: 604-224-6880  
E-mail: [dbuirinc@axion.net](mailto:dbuirinc@axion.net)  
Design: Diana McPhail

Streamline's goals are to communicate information on practical approaches to watershed restoration including the rehabilitation of stream channels, riparian zones and hillslopes, and to act as a link between geographically separated WRP proponents and their contractors by facilitating the sharing of information and ideas between the regions of B.C. We rely on our readers' participation. **Please send articles and project descriptions (with relevant photos and drawings), as well as information for our "Update" section. We reserve the right to edit submissions for appropriate content, style, and relevance to the Technical Bulletin.**

WRP Publications, Technical Circulars and Videos may be ordered from:  
**Queens Printer**  
PO Box 9452 Stn Prov Govt  
Victoria B.C. V8W 9V7  
Tel: 1-800-663-6105; or 250-387-6409  
Fax: 250-387-0388

Funding provided by  
Forest Renewal BC

