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.

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Seeding for Site Rehabilitation

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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

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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 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

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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.

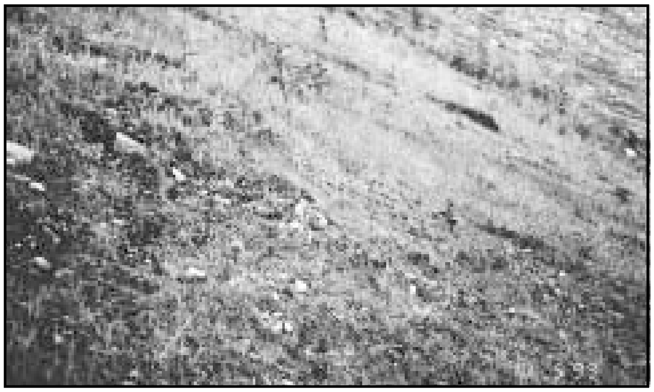

Figure 2. The plot in the foreground was dry broadcast, whereas the plot in the background was hydro-seeded with a heavy mulch application using the same seed mixture and fertilizer. Note that the hydro-seeded plot has a healthier vegetation cover with a greater species diversity.

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 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