MINE RECLAMATION IN BRITISH COLUMBIA: ACCOLADES AND ISSUES

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ABSTRACT

British Columbia leads the world in mined land reclamation. Effective programs for re-integration of the disturbed lands with the surrounding terrain have been developed. Strategies for replacement of substrates that provide suitable characteristics for plant growth as well as protection and isolation of underlying mine wastes from the environment have been applied at a number of mines in British Columbia. Effective systems for the establishment of an appropriate vegetation cover on the reclamation sites are as varied as the biogeoclimatic zones in which they are applied. Similarly, diverse systems for reclamation monitoring and maintenance have been developed at some mines. However, there are mines and sites on some mining properties where large waste rock dumps stand in stark contrast to the surrounding landscape. At some mines or on some sites within a particular mine, waste rock and/or tailings have not been adequately covered with a suitable growth medium and the growth of vegetation is patchy or non-existent. Similarly, although effective revegetation strategies have been applied at some properties, there are sites where dense stands of agronomic grasses and legumes all but preclude the re-establishment of appropriate successional trajectories on the disturbed lands on these sites and the prospects of a self-sustaining vegetation cover are a distant dream. This paper explores the accomplishments and pit-falls in mined land reclamation in British Columbia.

INTRODUCTION

Reclamation of lands disturbed by mining has developed since the late 1960's and early 1970's from a relatively simple process of re-shaping the lands followed by revegetation to a sophisticated process of re-establishing appropriately shaped landforms for the post-mining land uses, creating a suitable growing medium with appropriate soil micro-organisms, and establishing a successionally appropriate vegetation cover. Recognition that the simple concept of developing 'self-sustaining, biologically productive ecosystems' on the reclaimed lands requires more than simply picking up the nearest bag of seeds and spreading them on the mining wastes has lead to reclamation programs where an integration of a diversity of disciplines are employed in this final stage of the mining process. This process of reclamation development has not been without setbacks and problems and it is instructive to look at the techniques and systems for mined land reclamation that have been applied in the past so that effective methods can be emulated and problems can be avoided.

In the early days of mine reclamation, little consideration was given to the eventual need for reclamation in the design of the mine. Designing for closure, a term introduced by Brodie et al (1992) but implicitly applied in early mining and reclamation plans (Jordan and Hoffman 1977) has developed as an integral part of the mine design process. A balance between keeping the costs of mining reasonable and allowing for effective reclamation at the close of mining activity in an area is essential for the continuation of profitable mining in the Province. The development of wrap-around waste rock dumps is an excellent example of a waste disposal strategy that is cost-effective and allows for efficient waste resloping following mining (Milligan and Berdusco 1978). In addition, implementation of wrap-around waste dump construction allows the upper areas to be reclaimed long before mining at the lower elevations is complete to the benefit of biota that have been displaced by mining (Fraser 1984). Reclamation has become an important part of mine design, with a concurrent reduction in overall costs for both mining and reclamation.

Recognition that soils play a critical role in the establishment of productive self-sustaining vegetation cover lead to detailed studies of mine soils and soil processes (Thirgood 1977; Fyles 1984). In addition, the importance of soil fauna was recognized (Lawrence 1984). Studies that focused on the role of woody debris and soil surface materials in establishing appropriate soil fauna were conducted (Fyles et al 1981) with the results incorporated into the reclamation prescriptions for a number of sites (Freberg and Gizikoff 1999). In addition to their role in the biological aspects of mine reclamation, soil materials are used to seal reactive waste rock and tailings and to minimize development of acidic drainage from mines (Gallinger 1988).

Establishment of a productive, self-sustaining vegetation cover on the lands disturbed by mining is an important part of most reclamation programs. There was a need for development of innovative techniques for vegetation establishment under the harsh conditions found at some mines (Smyth 1995). Creation of productive forests also presents challenges that are being met by novel approaches (Straker et al 2002). Similarly, special vegetation techniques have been applied at a variety of locations and have resulted in cost-effective solutions to revegetation challenges (Polster 2002). Establishment of trees and shrubs on mined lands has been challenged by competition from seeded grasses and legumes (Macyk and Belts 1995) as well as by rodents that hide in the grasses and legumes (Green 1982). Techniques for propagation of native woody species have also presented challenges (Marchant and Sherlock 1984)

Monitoring and maintenance of the reclaimed areas has also evolved over the years. Reclamation monitoring has been used to provide feedback for improvement of reclamation programs. Although most reclamation practitioners seek to minimize the need for continued maintenance of the treated areas, maintenance has been part of many reclamation programs. Monitoring and maintenance of reclaimed areas is an important part of mine reclamation, from casual observations to the detailed surveys used to determine levels of standing crop, species compositional shifts and to project productivity values. Careful monitoring can provide important information for enhancement of reclamation programs.

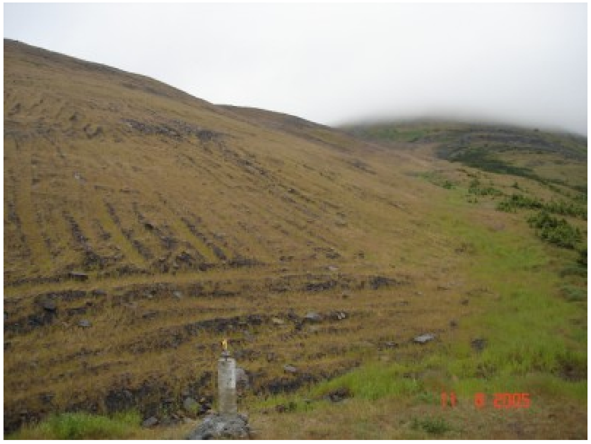
The following sections of this paper provide a synopsis of reclamation experience, good and bad, within the broad categories of landforms, soils, vegetation and monitoring and maintenance. Information and improvements can be gained from looking at reclamation efforts that have failed to achieve the desired results as well as those reclamation works that have met or exceeded expectations. This paper therefore presents both the successful strategies that have been employed to reclaim British Columbia's mines as well as those treatments (or lack thereof) that have not resulted in successful reclamation. The information is presented to provide opportunities to learn from the failures and to emulate the successes and not to point out deficiencies or shortcomings in specific reclamation programs. Reclamation experiences, both good and bad, can be instructive as new mines are opened and new challenges are faced at existing mines.

LANDFORMS

Major open pit mining in British Columbia is all about moving massive quantities of material in the most efficient and effective manner possible. Overburden and waste rock must be moved to uncover the ore. This waste material must be moved aside to allow the ore to be extracted. Where possible, the use of gravity to move materials is most effective hence the tendency to create large waste rock dumps where gravity is used to move the material away from the active mining area. Large waste rock dumps generally form with flat tops and sides sloped at the angle-of-repose for the waste material, typically about 37 degrees (Photograph 1). Although these structures provide efficient means of disposal of waste material, the compacted top surface and the angle-of-repose slopes presents challenges for effective reclamation. The heavily compacted dump platforms are impenetrable by roots and moisture while the unstable side slopes resist vegetation establishment. In addition, the angle-of-repose slopes are only marginally stable. Slumping and slides associated with angle-of-repose slopes are common and can destroy reclamation efforts or large areas of otherwise undisturbed land. The development of wrap-around dumps solved this problem (Milligan and Berdusco 1978; Berdusco 1980) and allowed large angle-of-repose waste dump slopes to be broken into small sections so that they could be effectively resloped and revegetated (Photograph 2). In addition to the advantages achieved in resloping and revegetation, creation of wrap-around dumps allows mid-slope access to be established so that reclamation activities such as woody species planting, maintenance and monitoring can be easily conducted.

Photograph 1. Large waste rock dumps present reclamation challenges.

Photograph 2. Wrap-around dumps allow effective resloping and access.



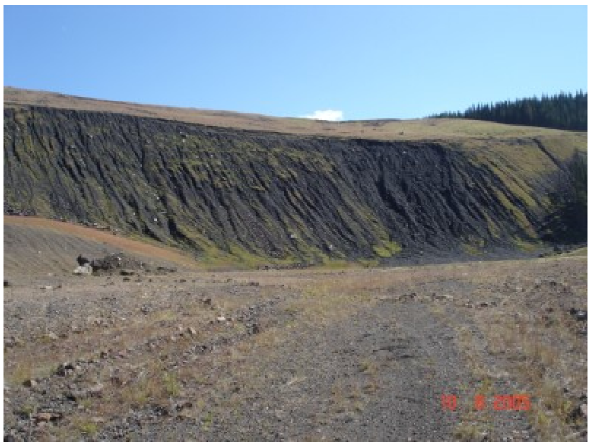
Photograph 3. The waste dump (left) blends effectively with the rolling terrain (right).

Natural landforms support naturally productive ecosystems. Creation of mining landforms that mimic the natural landforms in the area provides the most effective means of re-integrating the mining disturbances with the surrounding lands. Flat topped dump structures with uniformly sloping sides (Photograph 1) will always look like a mine waste rock dump while dump systems that blend with the local topography will soon disappear from view (Photograph 3). Re-integration of the mining landforms with the local topography enhances wildlife use of the reclaimed area (Fraser 1984). Where specific landscape features such as escape terrain coupled with forage production and thermal cover are used by wildlife, establishment of movement corridors between these can be very important to productive wildlife use of the reclaimed area (Photograph 4). Waste dump configurations that provide movement corridors for wildlife can be an important contributor to the success of the reclamation program. Designing these features into the final landscape through the mine design process allows for efficient and orderly reclamation when the time comes (Gadsby 1992).

Photograph 4. Escape terrain, nutritious forage and thermal cover are important ingredients for productive wildlife habitat.

Naturally shaped landforms provide the foundations for productive ecosystems. Where landforms are created in the mining process, there is a need to consider how these will function within the context of the surrounding terrain and the proposed end-land uses. Steep south and southwest facing slopes can provide important wildlife habitat while broad flat or slightly rolling topography can serve to form the foundation for productive forest lands that can be easily harvested in the future. Consideration of how the landforms will be used will help determine the reclamation treatment.

A variety of resloping procedures have been applied at mines throughout British Columbia. Trials to determine the most effective resloping procedures have been conducted (Popowich 1978). Partial resloping, where the surface fine textured materials are pushed over the angle-of-repose slope, has been tested at several mines in an effort to avoid the high cost of full waste rock dump resloping. Although this approach to reclamation is appealing, the inability to create dump surfaces that are resistant to erosion and that can support productive vegetation covers makes partial resloping in-effective for reclamation in British Columbia. Partially resloped waste rock dumps have not been shown to sustain a cover of vegetation that will achieve end-land use objectives. The fine textured materials that are pushed from the top of the dump are sensitive to moisture and will not stand at the same slopes as the underlying coarse rock. In addition, because the surface is unstable, an erosion controlling cover of vegetation is difficult to establish and excessive erosion is commonly seen on these slopes. Because the slopes are composed of fine textured material, erosion can occur more easily than with coarse rock. Erosion and failures are nature's way of flattening the slope so that vegetation can establish (Photograph 5). However, excessive erosion prevents the establishment of vegetation and reduces the productivity of the site. In addition, these steep slopes present a barrier to animal movement.

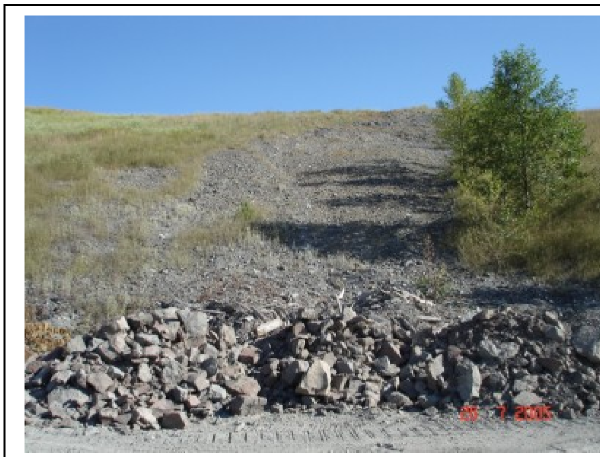


Photograph 5. Partially resloped waste rock dump with an angle-of-repose slope.

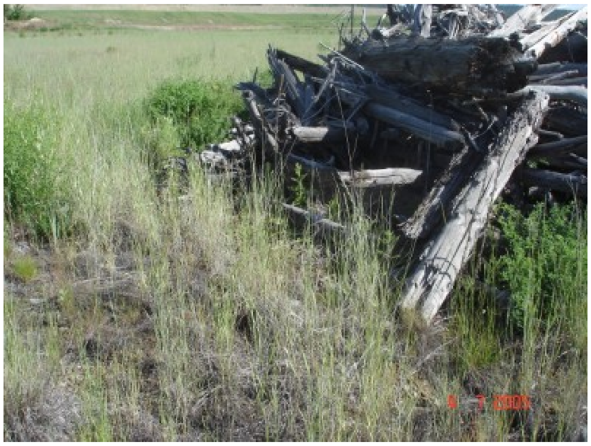
SOILS

Soils form an essential part of the reclaimed environment, whether formed from the breakdown of the waste rock, as is the case in most coal mines, or from salvaged surficial materials and applied as a top dressing on the waste rocks. Within the context of this discussion, soils include all of the unconsolidated material that is found over the bedrock in a mining situation. They include the topsoil (LFH, A, B and C soil horizons), and unconsolidated overburden, in most cases, glacial till. Soils form the foundations of productive ecosystems and are therefore an important part of the mine reclamation process.

Soils can also be used to seal reactive waste materials, rock and tailings, from the external environment to minimize the extent of reaction and thus acidic drainage (Photograph 6). Elaborate systems of sealing the wastes have been developed at some mines. Capillary breaks have been used on top of reactive tailings materials to prevent acid migration into the soils on top (Gardiner 1977). In some cases, treatments consisting of compacted and un-compacted till as well as till amended with bentonite and/or flyash have been applied (O'Kane et al 2001). Where phytotoxic materials are being covered the soils must act as an independent system and they must be deep enough to provide the required moisture storage for plant growth. In areas where ample rainfall keeps soil moisture movement in a downward direction, a capillary break is not required, although ample depth for plant root systems is needed. Care must be taken in these circumstances to avoid excessive competition between the species that are established on the surface.

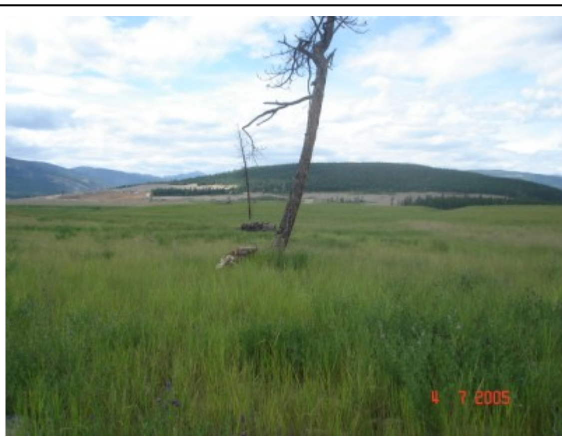


Photograph 6. The lack of vegetation cover on this strip of waste rock dump is due to a lack of till cover and the exposure of acid generating waste rocks.

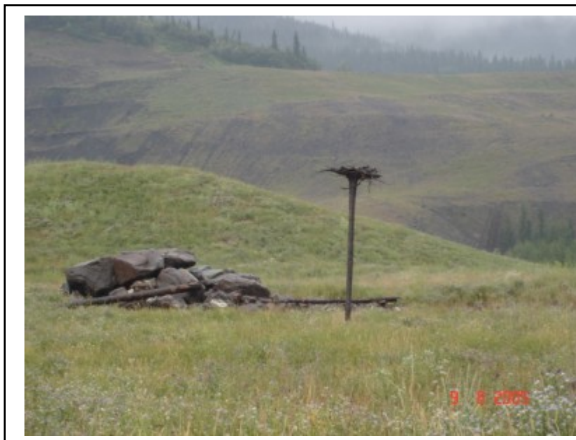


Photograph 7. Woody debris can provide habitat for soil biota and larger animals as well as aiding in re-establishment of nutrient cycling.

Woody debris, either in piles or scattered, has been used to enhance soil conditions by providing a diversity of conditions for soil biota (Curran and Dykstra 1997). Healthy soil biota populations have been implicated in the development of effective nutrient cycling systems on the reclaimed lands (Lawrence 1984). Nutrient cycling is critical to the sustainability of the reclaimed areas (Fyles 1984). In addition to aiding in soil development and the establishment of nutrient cycling on the reclaimed lands, woody debris also provides habitat for wildlife (Fraser 1984). The use of large woody debris in the reclamation of disturbed lands also provides a convenient solution to the disposal of slash and roots that are generated during the clearing of lands for mining (Photograph 7). Whole trees can be used on reclaimed lands to provide wildlife enhancements. Trees have been used in both upright and upside down positions (Photographs 8 & 9). Creative use of woody debris provides solutions to disposal problems while enhancing the wildlife use of the reclaimed areas. By looking at the wastes generated by clearing operations as resources to be used in reclamation of the lands disturbed by mining, benefits can be derived from what was once considered only a cost. Woody debris can help to bridge the gap in available habitat that is created when large areas are cleared for mining. The loss of standing snags with the attendant loss of cavities for nesting birds has a ripple effect throughout the ecosystem. Return of this structural component of the ecosystem can help bridge this gap and the services that this ecosystem component provides.



Photograph 8. Snags created from dead trees help to re-establish woodpecker and cavity nesting bird populations as well as providing perches for raptors.



Photograph 9. Upside down trees have been used on some reclaimed sites to encourage raptor nesting while the adjacent rock pile provides habitat for small mammals that are used as prey by the raptors.

VEGETATION

Vegetation reflects the conditions under which it is growing. A site with suitable, stable substrates will show superior growth compared to a similar site without appropriate soils or where the soils are unstable and are continually eroding. Similarly sites that are compacted or are excessively porous and therefore droughty will not support as good a vegetation cover as sites where the soils are loose and friable and where there is sufficient fine textured or organic material to prevent summer drought. Vegetation can therefore be used as an indicator of effective reclamation. If the site supports a healthy, diverse vegetation cover, it is probably effectively reclaimed (Photograph 10).

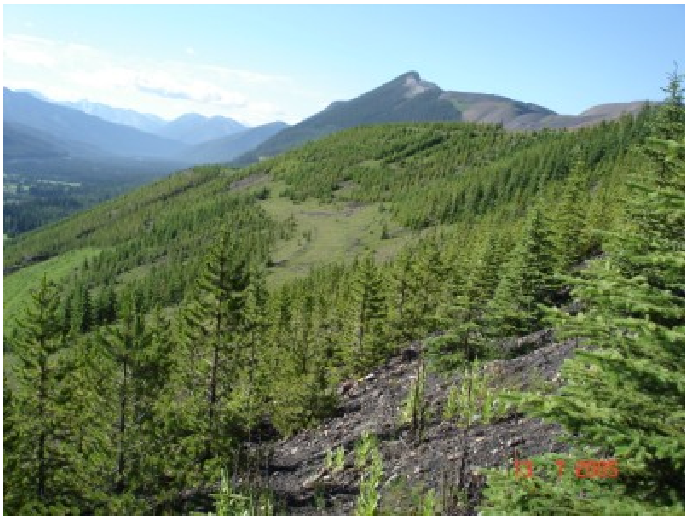
Photograph 10. A healthy vegetation cover composed of a broad diversity of species indicates effective reclamation has occurred on this waste rock dump slope.

A wide variety of strategies have been applied to the establishment of vegetation on mined lands in British Columbia. Traditionally, revegetation consisted of establishing a cover of seeded grasses and legumes on the reclamation site with the possible subsequent planting of trees. However, this approach has provided only limited success in restoring productive vegetation covers that meet the prescribed end land uses and productivity values. Where substrates have been productive, dense stands of grasses and legumes have been established to the detriment of any woody species that might be later planted on the site (Green 1982).

Native species islands have been used to establish native species in reclaimed areas dominated by seeded agronomic species with the intention that the native species that compose these islands will spread and will eventually cover the reclaimed land (Smyth 1995). Shrub islands assist in re-establishing wildlife habitat on the reclaimed lands by providing cover for animals within a sea of seeded grasses and legumes (Jones and Densmore 1991). Although the long-term results of the use of native species islands has yet to be determined, the growth of individual plants (Photograph 11) used in the islands has, in some cases proven to be very good (Sharman and Smyth 2002).

Photograph 11. Growth of Alpine Hedysarum within a native species island provides an indication that this strategy for vegetation establishment is effective.

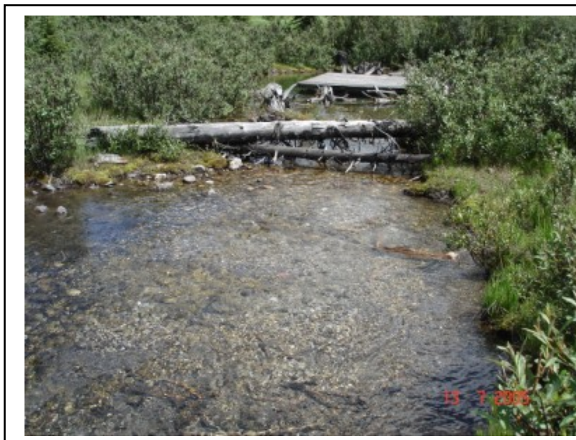
Re-establishment of productive forests on lands disturbed by mining is a common goal of many reclamation programs in British Columbia. Systems that make use of the soil enhancing properties of nitrogen fixing species have been applied at several mines where productive forests are the desired vegetation cover. In some cases, conflicts between tree growth and the production of nutritious forage for ungulates occur. The establishment of the trees first followed by seeding in non-aggressive legumes has been shown to be an effective strategy for productive forest establishment (Photograph 12) (Berdusco et al 1997). In other cases, productive tree growth can begin with nitrogen fixing trees (Photograph 10) with the expectation that later successional species will establish as the initial cover ages.



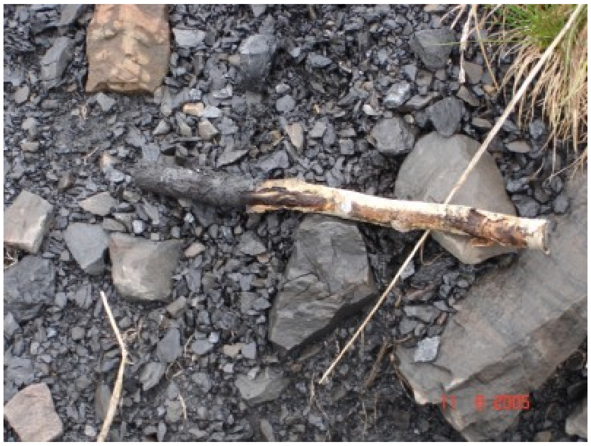
Photograph 12. Establishment of productive forests on mine wastes can be accomplished where slopes and substrates are suitable.

Establishment of productive forests on sites where substrates are nutrient poor or where compaction or other adverse soil conditions restricts growth is less successful. There are many sites where sufficient consideration of growing conditions has not been given prior to tree planting and the plantation fails to perform satisfactorily (Photograph 13). In addition to adverse site conditions that limit the success of tree planting efforts, competition with seeded species can cause problems with tree survival and growth. In some cases poor nutrient status of the substrate limits tree growth even with appropriate legumes on the site.

Photograph 13. Poor colour and limited leader growth are indicative of poor growing conditions for this planted spruce tree.



Photograph 14. Shrubs and large woody debris are important contributors to the aquatic habitat on this constructed stream.

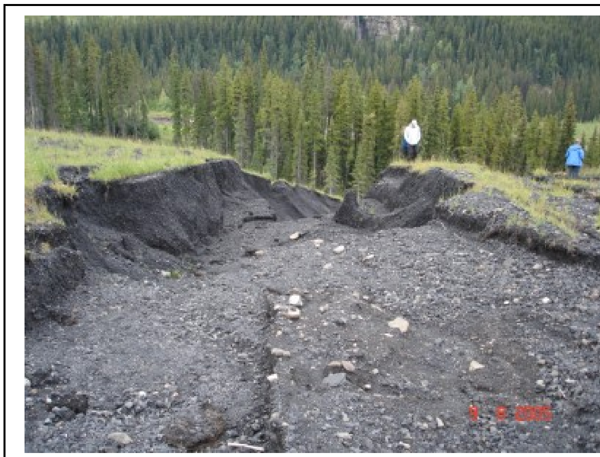


Photograph 15. Failure of this cutting to establish is thought to be due to insufficient planting depth and the insufficient length of the cutting.

Woody shrubs are an integral part of some reclamation programs. Shrub islands are used to provide habitat for wildlife while planting of shrubby species within the riparian areas of constructed streams can enhance the fisheries values of the stream (Photograph 14). Selection and propagation of suitable shrub species can present challenges as some species that might be expected to do well are difficult to establish while others can be established easily (Marchant and Sherlock 1984). The use of willow stem cuttings for establishment of shrubby vegetation can be a very effective technique. However, an understanding of the factors that allow successful establishment of cuttings is needed to ensure success (Photograph 15). Dormant stem cuttings that are at least 2.5 cm in diameter and 40 cm long and are buried at least three quarters of their length in moist soil will have the best chance of success (Polster 2005). Understanding the requirements of the plants being planted and the requirements of the planting methods is essential to achieve success in woody species planting programs.

Effective revegetation requires that all other aspects of the reclamation program, from landform development to substrate establishment are implemented appropriately. Good tree growth is impossible on compacted substrates. Similarly, constantly eroding slopes will not support a good vegetation cover. Once these aspects of the reclamation program are effectively addressed, then revegetation can be conducted with some assurance of success.

MONITORING AND MAINTENANCE



Photograph 16. Drainage from a large footwall above resulted in erosion of these coarse reject materials.

The successful establishment of vegetation on mine sites often requires some form of monitoring and maintenance. Although the use of annual applications of fertilizer has been discontinued at most mines, some maintenance in the form of nutrient enrichment or additional vegetation establishment is routinely conducted at most successful reclamation sites. There are cases where significant damage has occurred due to a lack of frequent site inspections. Drainage can be a very challenging issue on mine sites as the new landforms and landscape shapes adjust to the precipitation and run-off from new slopes. The compacted surfaces of waste rock dumps can prevent infiltration of moisture and can result in significantly increased overland flows. Similarly, footwalls can create large impervious surfaces that can channel water onto poorly protected waste dump slopes (Photograph 16).

Formal monitoring programs can provide insights into the effectiveness of reclamation procedures (Sharman and Smyth 2002). Determination of the expansion rates of native species islands or the growth rates of established forest trees (Straker et al 2002) can provide clues that can be used to determine modifications to the reclamation treatments. Opportunities to share monitoring results such as through the annual reclamation symposia can provide benefits to all. Although the mining industry is a competitive industry, reclamation improvements can be enjoyed by all when details of reclamation successes and failures are shared. Monitoring at one mine can provide information that may be useful at other mines.

CONCLUSIONS

British Columbia is a leader in the reclamation of lands disturbed by mining. Innovative practices have lead to reclamation successes under some of the most severe conditions in the world. Some treatments, however, have not succeeded in effectively meeting reclamation expectations. For instance, when appropriate waste rock disposal designs are not applied in a timely manner, severe reclamation conditions can result. The challenges of resloping waste rock dumps that exceed 100 m in height are being faced by a number of mines in the Province. Seeking to enhance the profitability of mines during periods of low prices by “high-grading” waste disposal methods can have dire consequences for reclamation and the sustainability of mining in the long term.

Effective systems of waste capping and sealing have been applied at many mines in British Columbia to provide a rooting medium for plants as well as to prevent moisture and oxygen from reaching reactive waste materials. In some cases, the failure to recognize the extent of the reactive materials or the need to provide substantial moisture holding capacity for the vegetation, has lead to insufficient soil materials being used as a waste capping or sealant. Soils also play a vital role in sustaining plant growth. Re-establishment of nutrient cycling systems is a critical part of effective reclamation. Large woody debris has been shown to be an important ingredient in the establishment of productive, self-sustaining plant communities in areas below treeline where woody species comprise a significant part of the ecosystem. Salvage and use of soil materials, including the woody debris that is associated with site clearing, is an important part of reclamation at many successfully reclaimed mines.

Revegetation of mining disturbances represents the culmination of all previous reclamation efforts. Once the disturbed sites have been reshaped and appropriate growth materials applied, revegetation efforts are undertaken. A wide variety of revegetation strategies have been applied to mines in British Columbia. Native species islands have been used to reclaim high elevation disturbances where agronomic species are difficult to grow. Shrub islands have been established on several mine sites to provide loci for shrub invasion as well as to provide wildlife habitat. Tree planting has been conducted at many mines in the

Province to varying effect. Re-establishment of productive forests continues to be an elusive goal at many mines.

Special woody species establishment techniques have been used at a variety of mines in British Columbia. Live staking using dormant willow and cottonwood cuttings can be an effective treatment for planting these species if correctly applied. Unfortunately, in many instances, poor implementation of this good idea has resulted in failure and a reluctance to further apply this useful technique. Tree planting with subsequent legume establishment has been used at a number of mines as a means of establishing `productive forests. Where soils are suitable and nutrient conditions are appropriate for plant growth this technique can prove very successful. However, as with any revegetation effort, where soils are excessively compacted, unstable or where dark substrates create excessive summer heat; poor results have been obtained with whatever planting treatment is applied.

Monitoring and maintenance are important parts of any successful reclamation program. Monitoring can be used to determine if there are things that need to be done to correct some problem or to re-align some ecological trajectory. Maintenance is needed where the treatment requires added support to become self-sustaining. The aim of most reclamation programs is to minimize the need for extensive maintenance over the long term. Hence species such as legumes, soopolallie, wolf willow and alder that fix nitrogen are popular on most reclamation sites. Monitoring and maintenance programs must be established early in the reclamation planning phase of the work so that when the time comes for implementation, these programs will be well established.

Successful reclamation in British Columbia has been built on many years of research and practice. Sharing information through the Technical and Research Committee on Reclamation symposia continues to be an excellent means of disseminating valuable information on reclamation work in the Province. All reclamation practitioners benefit from this open sharing of important information. Successes as well as failures need to be included so that problems can be avoided and the successes can be copied. Continued research, particularly now that many reclaimed sites are maturing, provides unique insights into the ecological processes associated with reclamation in British Columbia and the pathways to success.

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