14.0 Reclamation and Closure

The role of reclamation and closure in any mineral exploration project can be regarded as the final chapter in the life of that project. When the exploration project develops further into a feasibility study or a full-scale mining operation, however, then the reclamation process undertaken at the exploration stage becomes the first step in the final rehabilitation of the mine.

There are many definitions used in describing reclamation and closure. These include:

- Decommissioning. This is the transitional period between the cessation of operations and the final closure of that operation.
- Reclamation. This refers to the physical aspects of earth moving, regrading and revegetation.
- Rehabilitation. Another word for reclamation, this term is used extensively in countries other than North America.
- Closure. This is a term reserved for the point in time when revegetation has been completed, waste materials have been removed to the extent practical, a final surface and ground water monitoring program has been initiated, and the maximum degree of passive management has been implemented.

14.1 Principles of Reclamation

Reclamation is the process whereby the impact created by exploration upon the environment is minimized, and where the environmental disturbance to an area is remediated to the point where the land:

- Is safe and stable
- Is restored as near as possible to its pre-disturbance condition
- Has its environmental values safeguarded
- Has an appropriate sustainable ecosystem

An integral part of an exploration program is to plan operational objectives in advance of any activity taking place. Operational objectives should also include a well-defined reclamation objective that is properly planned, in order to meet the criteria for success.

Include in the plan an appropriate final land use:

- Agreed to by the stakeholders
- Defined in consultation with relevant interest groups

To maintain or monitor that land use into the future, the plan needs to define the required:

- Financial commitment
- Level of management

Reclamation normally consists of a number of definitive steps that need to be implemented at appropriate times and at the appropriate level. These steps can be categorized into 4 major stages:

1. Baseline environmental studies and information gathering
2. Landform design and the reconstruction of a stable land surface

3. Revegetation or the development of an alternative land use on the reconstructed landform
4. Environmental audit to monitor the success of the rehabilitation process

These stages normally can be applied to most activities likely to be encountered during an exploration program.

Proper project closure is therefore the result of a combination of well-planned objectives, long-term commitments, and multi-party cooperation. Public education, in addition to participation, is a major factor because in the absence of knowledge, apprehension resides.

14.1.1 Objectives of Reclamation

The objective of rehabilitating a typical exploration site is to minimize long-term environmental liability by:

- Attaining regulatory compliance
- Maintaining geotechnical stability
- Restoring native ecosystems
- Reclaiming to a pre-existing land use
- Striving to achieve a more beneficial land use
- Reducing the social impact on local communities

Successful rehabilitation must be sustainable in the longer term, and requires an understanding of the basic concepts of soil conservation, slope management, plant succession and biodiversity. In addition, use professional practice project management concepts to ensure the program's complete success. Project closure is a "whole of project life" process involving:

- Stakeholder Engagement. The identification of stakeholders and interested parties is an important part of the process.
- Planning. Closure planning is required to ensure that closure is technically, economically, and socially feasible.
- Provision of Funding. A cost estimate for closure should be developed from the closure plan.
- Implementation. The implementation of the closure plan should reflect the different stages of the operation.
- Standards and Completion Criteria. Completion criteria are specific to the project being closed, and should consider its unique set of environmental, social, and economic circumstances.
- Mining Title Relinquishment. A responsible authority should be identified and held accountable to make the final decision on accepting closure.

14.1.2 Commitment to Reclamation

A commitment to reclamation is often required as an integral part of both project planning and statutory permitting. To fulfill that commitment, be prepared to assign resources to the reclamation program. This commitment must be fully realized at both the management and operational levels of the exploration activity, in order to minimize the long-term and the short-term environmental and economic liabilities.

If the project extends beyond the exploration phase, deviation from the management program over time, inadequate baseline studies, and inadequate field monitoring will likely result in increased costs at closure. A commitment must be made, not only to the overall closure approach or concept if a mine develops, but also to the individual components of that development. This involves initiating ongoing monitoring programs early on during the exploration phases of the project.

An environmental audit system offers the best approach toward maintaining a commitment to closure. Many companies have some form of audit program in place that involves both internal and external technical and legal experts. It is important for an audit program to commit to:

- Ongoing revegetation studies
- Ongoing surface water quality studies
- Ongoing ground water quality studies
- Ongoing refuse disposal
- Ongoing erosion control
- Maintenance of topsoil stockpiles
- Maintenance of backfill material
- Monitoring of effects upon flora and fauna
- Monitoring of any social disruption to local inhabitants

Also, it is important to make a commitment to the continued evaluation of reclamation alternatives, as well as to the continued education of environmental personnel and the public, regarding the potentially changing reclamation requirements. If companies, and the industry as a whole, do not commit to the conceptual and cash requirements of closure and reclamation, then some other entity is likely to do so, either through litigation or legislation.

Figure27: With proper capping and, if necessary cementing, seepage of groundwater with high metal content can be avoided. © Noranda/Falconbridge.

14.1.3 Cooperation in Reclamation

Make every effort to establish both internal and external cooperation and understanding between the participating stakeholders in the reclamation process. It is also the company's responsibility to ensure complete cooperation between operational people and corporate personnel in the office, so that everyone has a proper understanding of all the environmental concerns. It is also a good idea to promote complete cooperation and understanding between the technical and non-technical staff within the individual operation.

The company is responsible for making sure that there is always cooperation and information exchange among:

- The exploration operation
- The community
- The regulatory agencies

Without this cooperation and information exchange, the reclamation process may become very time-consuming due to:

- Mistrust
- Inflexibility
- The misinterpretation of concepts and actions

The objectives must always be clearly set out for all stakeholders.

From a cooperation, coordination, and communication standpoint, the global exploration community must share their ideas and their reclamation plans, and recognize that good ideas may come from elsewhere. In this era of instantaneous electronic communications, there is no excuse for any lack of information exchange.

It is important to recognize that the future success of mining will not be tied to the promises made during permitting, or to the actual environmental, health, and safety record compiled during any operations. It will be tied to the condition of the project site after closure.

Consistent cooperation, coordination, and communication result in good exploration and serve to minimize future problems.

14.2 Planning and Timing

Develop a conceptual reclamation plan which can be reviewed on a periodic basis, as the project progresses from the early exploration stage into advanced exploration, feasibility and even beyond. If there is no well-defined and dynamic reclamation plan, an environmental assessment or an environmental impact study may be imposed as a legal requirement, prior to the abandonment of the project.

It is necessary, therefore, to develop and periodically review the reclamation plan and to be aware that this approach has become a standard or required practice in many parts of the world.

The following factors are important when considering reclamation plan options:

- Public safety hazards and risks
- Ecological compatibility
- Potential area of substantial disturbance

- Community expectations
- Future land use and resource demands
- Aesthetics
- Planning and timing

14.2.1 Reclamation Plan

Prior to the commencement of any exploration work, hold a planning session to consider the environmental aspects of the project, and:

- Identify those sensitive environmental features that may require some form of protection, prior to the start of the project
- Consult with appropriate stakeholders, such as local inhabitants, aboriginal or native groups, hunters and trappers organizations, and local regulatory authorities (e.g., Departments of Fisheries and Oceans, Wildlife, Natural Resources)
- Identify what baseline environmental studies are required for the level of work to be undertaken (e.g., burial or sacred sites, harvesting needs, wildlife and floral habitat, water testing)

Where baseline studies are required, prior to any substantial disturbance of the surroundings, consider sampling the:

- Water
- Soil
- Air
- Vegetation
- Wildlife habitats

Also:

- Ensure that workers are familiar with environmental obligations, are aware of applicable regulatory requirements and are properly trained to carry out any remedial procedures pertaining to environmentally related situations if they occur (e.g., fuel spills)
- Ensure that the exploration program is designed and budgeted to take into account all potential sensitivities associated with native lands, archaeological sites, and other land users

Also be aware of the special care and planning required for exploration activities undertaken in or close to certain habitats, such as:

- Dunes
- Coasts
- Permafrost areas
- Marshes
- Bogs
- Lakes
- Streams
- Rivers
- Deserts

Have a plan for all stages of the program, detailing how it is to proceed from the planning stage, through the first reconnaissance, follow-up, advanced exploration (including evaluation), and finally to closure.

In this plan:

- Include details of how all sites are to be disturbed and then restored, and how runoff and erosion are to be controlled, where applicable.
- Ensure that contractors utilized for such activities as drilling, excavation, geophysical surveys, and helicopter use, etc. are familiar with, and comply with, environment policy and the plans for reclamation at the closure of the project. It is important to ensure that they minimize their environmental disturbance, in order that the reclamation program can be carried out successfully.

14.2.2 Timing

Timeframes for reclamation can be quite variable, as they depend upon the regulatory requirements that exist in a particular state or country. Initiate an educational program for the public and for the exploration personnel as the project closure period approaches, in order to satisfactorily address the reclamation concerns of all interested parties. Many exploration programs are multi-year, and may involve different activities each year.

In the educational program, focus on the current year's plans; leave the more distant future plans, which are dependent upon results, in an outline form. If the project proceeds to the feasibility stage or beyond, it would then likely require a more formal and separate plan. This would include a site-specific Environmental Management System (EMS) and Environmental Management Plan (EMP), incorporating all the legal requirements for project reclamation and closure.

Conduct monitoring programs to gather the information necessary to make longer-term predictions of impact, particularly as monitoring requirements may change over time (e.g., analytical detection limits are lowered, new legislation is enacted). Initiate these programs as early as possible at the commencement of the project, and continue them throughout the life of the project.

14.3 Site Preparation

Prior to the commencement of any exploration activity, assess the impact that this activity will have upon the environment. Impacts that change conditions that will affect project objectives are also the environmental impacts that will affect the reclamation plan and any site preparations that are required. The impact assessment will allow the program to minimize environmental disturbance, and ensure that proper closure can be achieved at the end of the project.

Factors to consider in the assessment include:

- Physical stability. Engineer buildings, structures, slopes, underground openings, etc., so as not to pose a hazard to the public health and safety, and to stop any material eroding from the land to waterways at concentrations that are harmful.
- Chemical stability. Stabilize minerals, metals and other contaminants. They and their weathering, oxidation, or leaching products must not transport contaminants in excessive concentrations into the environment.
- Land use. The abandoned site should be able to be reclaimed to its pre-activity condition, to conditions that are compatible with the surrounding lands, or to an alternative

productive land use agreed to by other stakeholders. Generally this will require the land to be aesthetically similar to its surroundings and to be capable of supporting a self-sustaining ecosystem typical of the area.

- Sustainable development. Maintain elements of the site development that contribute to the sustainability of social and economic benefits, and transfer them to succeeding custodians.

The assessment of these types of impacts and closure factors must address the specific site requirements for the exploration activity being undertaken, and the particular climatic region involved. It is important to anticipate, as early in the process as possible, the potential future impacts, risks and liabilities so as to plan for their elimination or minimization.

14.4 Landforms, Stability, and Land Use

A major factor to consider during exploration site reclamation planning is to anticipate the shape of the final landform and identify those factors that will impact on that final landform.

Develop a clear understanding of the desired post-activity land uses expected by the various stakeholders, before planning for acceptable rehabilitated landforms. The final landform will also affect the types of revegetation processes and species to use to ensure long-term stability and erosion control. Consequently, the most appropriate option for land reshaping will vary from project to project, depending on a range of factors including:

- Legal requirements
- Climate
- Topography
- Soils
- Community views

Each of these is discussed in more detail in the following subsections.

Landform and land use are closely interrelated. The philosophy of returning land as closely as possible to its original landform and use applies to the industry throughout the world, and with good reason. There are many factors - such as community expectations, compatibility with local land use practices and regional infrastructure, or the need to replace natural ecosystems and faunal habitats - which all support returning the land as closely as possible to its original appearance and productive capacity. In most cases, however, it is up to the company to decide the final landform and land use.

14.4.1 Legal Requirements

The conditions attached to approvals, exploration leases, and various subsidiary licenses and permits may specify certain limitations. These can include maximum slope angles, the provision for surface drainage, the salvage and use of topsoil, and the choice of vegetation species to use in reclamation. These conditions will set minimum parameters for landform design.

The conditions imposed by government planning instruments, such as state, regional and local environmental plans, and council zoning, may limit the range of land uses available after rehabilitation; it is necessary that everyone is aware of these. In particular, planning instruments may restrict the visual impact of disturbed land, and may require the preservation of items of cultural and heritage value, and dictate the vegetation species that can be used for rehabilitation.

14.4.2 Climate

The annual rainfall, its type and distribution, has perhaps the greatest influence on the design of stable landforms and drainage systems. Take careful account of the local conditions in planning reclamation. Together with the temperature regime, rainfall determines the type of vegetation that can be grown successfully. Monsoon weather systems, dominated by high intensity storms, will require that special attention be paid to drainage and to the early stabilization of exposed slopes.

Winter or summer dominance of the rainfall has an obvious effect on the type of vegetation grown and the timing of revegetation. The reliability of rainfall probably has the strongest climatic influence on vegetation and landform.

14.4.3 Topography

The most important components of topography are:

- Slope gradient
- Elevation
- Drainage density (the total length of natural watercourses per unit area)

Aspect, or the direction in which slopes face, also has a pronounced effect on localized temperature and moisture regimes, both of which can influence vegetation growth. While little can be done to alter slope aspects, it is important to be aware of the subtle changes that these may dictate in land use, species selection for revegetation, or the management for various parts of each site.

The angle and length of natural slopes within and surrounding the exploration site will influence the amount of reshaping necessary to achieve visual blending of the site. Slope angle, and the degree to which the land is dissected by drainage channels, will affect its suitability for alternate uses.

For example:

- Slopes above 8° (14%) are generally unsuited to regular cropping, due to high erosion hazard
- Slopes over 20° (36%) should not be subject to intense agriculture or grazing, and are more suited to revegetation with native species and a low-intensity land use

Drainage density is an important attribute in achieving long-term stability. The natural drainage pattern has evolved over geological time and is in equilibrium with the environment. The reclamation plan should take account of the drainage density prior to any disturbance, as this will provide a useful benchmark for the design of new landforms.

However, changes to elevation, slope angles and slope lengths brought about by exploration activities such as excavation, dumping, and reshaping may render the new land surface susceptible to erosion. This may necessitate incorporating changes from the original drainage density in order to achieve long-term stability.

14.4.4 Soils

The distribution and quality of soil types over any area that will be disturbed by the exploration program, will influence the volume of topsoil and suitable subsoil available for topdressing. Past land uses, the extent of historic erosional damage, salination, and the presence of weeds and other undesirable species will affect the rehabilitation value of the soil. This in turn will affect the choice of landform and its use in rehabilitating disturbed areas.

14.4.5 Community Views

It is important to take into account the views and expectations of the community, and especially of the people in the local area, when deciding landforms and uses. Pay particular attention to people with a special interest (e.g., those whose land may be affected by the exploration activity), and community groups (e.g., local wildlife, botanical and historical societies, Aboriginal communities), which may have strong preferences about the landforms and future uses of the site.

The local expertise of these people can be valuable for such things as advice on flood and drainage control, the collection of native species seed, as well as weed and feral animal control. Seek out community views on landform and land use in the consultation program during the early phases of project planning and design.

14.5 Soil Conservation

Most plants get their nutrients and water from the soil. Plants in turn are the main source of food for animals and birds. As a general rule, therefore, it is important to preserve soil – in particular topsoil – for reclamation use wherever possible, as it can be a valuable source of seed, nutrients, and microorganisms. The physical properties of topsoil can also be an advantage in providing a suitable microenvironment for seed germination, and in mitigating the problems of clay dispersion and surface crusting.

When stockpiling topsoil:

- Plan to respread or reuse the topsoil as soon as possible, to maintain seed viability, nutrient quality, and mycorrhizal (symbiotic) fungi activity.
- Store topsoil in low mounds of 1-2 m maximum height; do not store it in large heaps. (Good practice for topsoil storage height from various sources ranges between 0.6 m-3 m. The 1 m-2 m height has been suggested here as a reasonable midpoint within this range.)
- Locate the stockpiles where they will not be disturbed.
- Revegetate stockpiles to protect from erosion, discourage weeds, and maintain active populations of beneficial soil microbes.
- Consider by what method soil will be respread.

Make an assessment of the relative advantages of topsoil, compared to the material to be covered, in terms of its physical and chemical properties. Where topsoil is in short supply, give preference first to topdressing those areas most susceptible to soil erosion. These critical areas include newly formed watercourses, and areas where dense, high-quality vegetation is required. Consider separately stripping topsoil and subsoil, and replacing them in their proper sequence for areas of arable land where subsequent productivity is important.

It is paramount that soil be conserved to provide the ecological balance required to successfully rehabilitate the project area. The following subsections set out guidelines to consider in soil handling and treatment.

14.5.1 Soil Handling

Topsoil is often the most important factor in successful rehabilitation, particularly where the objective is to restore a native ecosystem. The term “topsoil” generally refers to the A1 horizon of the soil, which is usually darker than the underlying soil because of the accumulation within it of organic matter. The topsoil contains the majority of the seeds, other plant propagules (e.g., rhizomes, lignotubers, and roots), soil microorganisms, organic matter, and much of the more labile (more readily cycled) plant nutrients.

Some guidelines to help ensure successful topsoil handling include the following:

- Consider the thickness of both useful and unfavourable soil materials
- Check rooting depths in undisturbed soils, as they can be a useful guide to determining the thickness of soil materials worth salvaging
- Remove the complete A1 horizon
- Recover the top 100-300 mm of soil, when the A1 horizon is not obvious
- Do not include deeper soil layers with adverse chemical and physical properties (e.g., B horizons with a higher clay content, cemented horizons, subsoils with high concentrations of salts or carbonates)
- Use the subsoil as a substrate for rehabilitation, if the topsoil contains large numbers of seeds of undesirable species

Ensure that contractors are informed of the rehabilitation program. Pre-work site visits are valuable, to acquaint the equipment supervisor and operators with the identification of the soil layers that will need to be handled, especially the depth to unfavourable subsoil.

Develop a consistent method for locating separate piles of topsoil and less desirable fill materials. On level or gently sloping ground, for example, topsoil and excavated subsoil can simply be placed in the most convenient locations for respreading.

Other guidelines to follow include:

- Use excavators for excavations because of their greater flexibility in removing and placing soil materials. Front-mounted blade equipment is particularly unsuitable for construction on slopes because of its uncontrolled sidecasting.
- Minimize the inclusion of stumps and woody debris with topsoil.
- Ensure that topsoil piles are protected from wind and water erosion, and are not buried.

Avoid the handling of topsoil during wet conditions. Make sure that all excavations are backfilled in the reverse order of their excavation, which is subsoil first followed by topsoil. Scatter vegetation debris on the soil surface to provide some protection from erosion until vegetation is established.

When spreading stockpiled topsoil:

- Avoid creating either a smooth-graded or coarse, cloddy surface
- Ensure that the roughness of the final surface is suitable for the subsequent seeding and fertilization treatments

Where rehabilitation treatments will include both tillage and topsoil:

- Plan the sequence of operations to avoid recompacting tilled areas
- Use winged subsoilers to till under respread topsoil with a minimum of mixing

- Utilize excavators to respread topsoil and decompact in one operation, by tilling a strip just ahead of a windrow of recovered topsoil, which is then progressively spread across the tilled surface

In some cases, topsoil stockpiling may be impractical. For example, on very rocky sites it may be too difficult to separate and stockpile topsoil. A high rainfall area where the site is continuously saturated is also unsuitable for topsoil respreading.

14.5.2 Tillage

Tillage is a technique to use primarily to decompact the soil and to re-establish soil porosity, thereby allowing plant roots to penetrate deeper into the soil. It is generally accepted that increasing the rooting depth (usually to around 50 cm) is considered advantageous for plants, even though the natural vegetation may have originally grown on shallower soils.

Deep tillage has the added benefit of breaking up any impermeable layers and perhaps mitigating some of the adverse effects of the initial disturbance on the surface soils. Equipment used for tillage can vary greatly, depending upon the site requirements.
Examples of tillage equipment are given in the following subsections.

14.5.2.1 Winged Subsoilers

Winged subsoilers are effective and efficient tools for decompacting soils in rehabilitation work, if used by an experienced operator under suitable soil conditions. The winged subsoiler, with the wings set at the proper angle, lifts the soil and then allows it to fall back and shatter in place as the implement passes. A good subsoiling operation can leave existing vegetation sufficiently intact so it continues to grow.

On the better models of winged subsoilers, the wings can be adjusted to match soil conditions, particularly if the soil is dry, high in clay content, or is extremely dense. The shank spacing also can usually be adjusted, to accommodate different site sizes or road widths.

Even though the wings are independently mounted to prevent hang-ups, a subsoiler is often ineffective on sites containing large rocks (>50%) or buried logs. The winged subsoiler is the most effective implement for decompacting uniformly large areas that have similar soil conditions.

14.5.2.2 Excavators

There are many situations where hydraulic excavators are more flexible tools than winged subsoilers. Excavators are more readily available, and a number of attachments are available to achieve different soil reclamation objectives, including mixing, mounding, tilling, and spreading mulches.

A conventional bucket is suitable for a limited amount of tillage where soil with the correct moisture content can be lifted and dropped to achieve good shatter.

Various other attachments are also available including:

- Mounders
- Mulchers
- Rototillers

- Rakes
- Thumbs

Excavators are particularly well suited for the following types of operations:

- Reclaiming areas where access is limited to low ground pressure equipment
- Building and reclaiming excavated trails on steep slopes
- Continuous topsoil replacement and tillage, especially on sloping sites where material must be retrieved from sidecast piles or berms
- Loosening and filling in ruts
- Creating mixed mounds or individual planting spots to achieve reclamation objectives
- Achieving effective tillage where buried wood, stumps, or stones prevent the use of implements such as the winged subsoiler

14.5.2.3 Other Equipment

Several other types of mechanical equipment are available for soil rehabilitation. Most implements, however, are designed to create favourable micro-sites for planting, rather than decompacting extensive areas in a homogeneous fashion. Experience with the use of specific site preparation implements for soil rehabilitation is limited.

In specific circumstances, certain specialized implements may be useful for:

- Mounding
- Scalping
- Disc-trenching
- Mixing
- Ripping
- Ploughing

For example:

- Roadside areas that have shallow compaction might be disc-trenched to improve early revegetation and plant survival, especially if the areas are not sufficiently compacted to warrant subsoiling, or if the subsoiler cannot be used effectively
- Mounding may be a suitable treatment on heavily disturbed wet sites

14.5.3 Soil Adjuncts and Fertilizers

Soil adjuncts are materials that can be mixed into the soil to restore soil organic matter, long-term nutrient status or soil structure. Chemical fertilizers provide an efficient means of improving short-term nutrient status. Mulches protect the soil from erosion, conserve moisture, and moderate soil temperature. Each of these is discussed in the subsections that follow.

Except for chemical fertilizers, soil adjuncts are bulky and expensive to transport. Local availability will therefore be a key factor in determining their suitability for various uses.

14.5.3.1 Organic Soil Adjuncts

Organic materials from a variety of sources can be used as soil adjuncts, including:

- Topsoil salvaged from nearby construction sites
- Residual vegetation
- Manure
- Hay
- Straw
- Sewage sludge
- Municipal compost

Good reclamation projects take advantage of these materials as their availability arises. Consider the guidelines that follow in using these materials.

Topsoil

The most readily available organic material is usually the residual vegetation accumulated during the site construction. Large accumulations of material adjacent to roads and construction sites could be burned, depending upon local regulations and local customs in the project area, to provide ash that could serve as a soil amendment. Fine branches and foliage contain significant quantities of nutrients, and these can be mixed directly as a soil amendment to improve soil physical properties, enhance nutrient status, and to increase mineral soil organic matter content.

Depending on the size and shape of the materials, it may be useful to chip fine residues where equipment is available. The material salvaged from other construction projects (e.g., permanent roads, landings) can also be used to supplement materials present on the site.

Manure, Hay and Straw

Little planning is needed to use these materials. Manure provides a good source of organic matter and includes nutrients such as nitrogen, phosphorus, and potassium. Hay from local meadows is a particularly good resource, as it is unlikely to introduce any unwanted species. Sometimes mouldy hay can be obtained very economically. Straw is usually free of weed seeds and has an intermediate C:N (carbon to nitrogen) ratio that is higher than hay, but lower than woody residues. (Note: The normal initial C:N ratio for a typical grass/leaf compost is 30:1, decreasing to about 10:1 as the composting process advances.)

Sewage Sludge

Sewage sludge has a high nutrient content, but is only available near population centres. Its high water content increases transportation costs, but specialized pumping and sprayer equipment allows for its application as slurry at some distance from roads. To protect ground and surface waters, consult with an expert to determine application rates, based on the nutrient and trace metal content of the sludge.

Compost

Municipal and other compost facilities may be available near populated areas. The nutrient concentration in composts is usually lower than those in sewage sludge, but nevertheless can be beneficial. Consider compost primarily as a source of organic matter, as opposed to a source of nutrients.

14.5.3.2 Chemical Fertilizers

A single, large application of chemical fertilizer is usually insufficient to restore the nutrient capital of a degraded soil. If the soil organic matter has been displaced or destroyed, and if only limited vegetation cover is present, then most of the nutrients added in a large application may be lost from the site.

Instead, use fertilization primarily to enhance the early establishment and growth of vegetation, which will restore soil structure and the content of organic matter.

Modest repeat applications may be needed until the internal nutrient cycle of the site is re-established and can meet the needs of the vegetation. However, do not consider a site adequately reclaimed if the survival of the vegetative cover depends solely upon its continued fertilization.

Most vegetation species commonly respond to nitrogen fertilization, and sometimes to:

- Phosphorus
- Potassium
- Sulphur

Any of these nutrients may be deficient in disturbed or reclaimed soils. Soil tests can be obtained from commercial laboratories to help determine fertilizer requirements for grasses and legumes. Fertilizer tends to be a small portion of total reclamation costs, so if nutrient deficiencies are anticipated, complete formulations are usually used at rates that approach safe maximums.

Application rates for initial fertilization will usually range between 30 kg-100 kg N/ha, depending upon the:

- Severity of nutrient depletion at the site
- Risk of runoff
- Amount and composition of seeded cover
- Reclamation objectives

Consult with an expert in the area for more information on typical fertilizer application rates.

Set maximum fertilizer rates to reduce the risks of damaging vegetation from:

- Over-fertilization
- Losing fertilizer through runoff or leaching

The risk of fertilizer damage increases greatly with:

- Decreasing moisture
- Increasing temperature

Higher fertilization rates can therefore be used without damaging seedlings in climates with higher precipitation. However, in wet environments, large amounts of fertilizer can be lost from recently disturbed sites that are:

- Low in organic matter
- Have limited vegetation cover

Alternatives to consider when fertilizing are to:

- Broadcast fertilizers on the surface

- Include fertilizers in a hydroseeding slurry
- Incorporate fertilizers if shallow soil mixing (<20cm) is part of the reclamation plan

Fertilizer can usually be applied at the time of seeding, ideally immediately after the seedbed is prepared. Higher losses of seed and fertilizer occur after the freshly prepared surface has been subjected to rainfall. Where vegetation is already established, apply fertilizer when growth is most rapid.

There are 3 general formulations that can be considered for reclamation work:

1 Nitrogen alone may be suitable for light disturbance.
2 Nitrogen plus high P_2O_5 is used to enhance the establishment of grasses.
3 $N=P_2O_5=K_2O$ plus low sulphur will supply all the major nutrients that are likely to be deficient. This is an economical and effective choice. High analysis granular fertilizers are preferred because of their lower transport and handling costs. A complete fertilizer with approximately equal concentrations of the macronutrients (such as 19-18-18, containing 19% N, 18% P_2O_5 and 18% K_2O) is desirable because of the low fertility of severely disturbed soils. Many possible formulations are available, and for most situations it is difficult to identify a clear advantage for any one recipe.

The best formulation to use will usually be dictated by:

- Cost
- Availability

Other points to consider:

- To avoid burning seed, do not mix seed and fertilizer together in the same bin for dry seed application
- Where there is a risk of drought, reduce the single application rate or incorporate the fertilizer into the soil
- If fertilizer supplies are limited, apply the fertilizer to critical locations, such as backfilled excavations and heavy use roads
- A second fertilizer application within 3 to 5 years after seeding will help severely degraded soils, by maintaining the vigour of grasses and legumes at critical erosion control locations
- Do not to apply slow-release fertilizers such as coated urea within 3 m of watercourses

14.5.3.3 Mulches

Mulches are non-living materials that can be spread over the soil surface to reduce erosion, and to aid plant establishment by conserving moisture and moderating soil temperatures. There are several types of mulches to select from, including relatively thick layers of organic material, manufactured mulch mats of various types, and thin layers of mulch primarily applied during hydroseeding. Each is discussed in more detail below.

Thick mulches

Materials suitable for thick mulches include:

- Residual vegetation (either fine-cut or chipped debris)
- Straw
- Hay

As a rough guideline, 5-10 cm is a sufficient depth for most sites. Decomposition occurs slowly because the mulched layer dries out repeatedly, but the materials will eventually contribute to the restoration of soil organic matter. Thick mulches imitate the ecological functions of a vegetation cover. Primarily consider them for drought-prone sites, but they may also be appropriate where soils are:

- Wet
- Cold

The mulch will keep fine-textured soils moist and soft, and plant roots may explore the interface between the mulch and mineral soil. Thick mulches will prevent the growth of:

- Grass
- Many weedy species

These are best used in combination with planted shrubs and trees.

Manufactured mulch mats

Various types of manufactured mulch mats are available, including plastic and fibre matting or netting materials. Some of these products can also aid in:

- Seed germination
- Vegetation establishment

For them to be effective, install mats in close contact with the soil surface. This may limit their suitability for the protection of roads where slopes often have rough surfaces.

Their ability to trap sediment and biomass is useful in:

- Building soil
- Improving surface soil conditions
- Restoring soil organic matter

Due to cost, the use of manufactured mats is most often limited to small, critical areas, such as ditch linings or culverts.

Thin mulches

Thin mulches are useful to aid the germination and establishment of grasses and legumes on drought-prone sites, highly erodible soils, unconsolidated (sandy) surface soils, and exposed slopes. Apply these mulches over the top of seed to protect it from desiccation and:

- Wind
- Water
- Gravity movement

Some types of light mulches need a tackifier (binding agent) applied with them, to prevent them from blowing or washing away. The most common mulching technique for use in combination with grasses and legumes is ground wood fibres, mixed with a green dye to improve visibility. Apply it with a hydraulic seeder equipped with a mechanical agitator that can also combine in the seed and fertilizer.

Thin straw mulches also offer excellent soil protection. These can be applied by:

- Hand
- Using a straw blower usually readily available through farm equipment suppliers

The use of a blower will speed application and ensure more even mulch coverage. Recommended rates range from a minimum of 2,000 kg/ha to over 5,000 kg/ha. For maximum effectiveness, however, spray a tackifier over the surface straw to hold it in place.

Mechanical means of anchoring straw are generally impractical for soil reclamation. These methods include:

- Discing
- Rolling
- Covering with netting

14.6 Revegetation

Revegetation is a fundamental part of all rehabilitation projects, and the type of revegetation techniques to use depends largely upon the rehabilitation objectives.

Rehabilitation objectives may include some or all of the following:

- Controlling surface erosion
- Increasing slope stability through the restoration of a root mat
- Creating, restoring, or improving soil structure
- Restoring biological properties affecting soil nutrient cycling
- Reducing recompaction after tillage operations
- Changing water relations on-site
- Conserving or adding nutrients
- Preventing the establishment of noxious weeds
- Maintaining or achieving aesthetics
- Producing a commercial forest or agricultural plot
- Restoring and providing habitat or forage for wildlife

If left unattended, bare soil will erode, recompact if already tilled, lose structure, lose nutrients, and undergo invasion by weed species. A wide variety of approaches to revegetation are available. Most traditional approaches have usually involved seeding a mixture of agronomic grasses and legumes to control erosion and establish vegetative cover.

Many more modern rehabilitation projects, however, may have more demanding objectives, such as re-establishing a recommended land use for forestry, cattle grazing, wildlife refuge, or native flora conservation area. Sometimes techniques required for one objective, such as developing complete ground cover to prevent erosion, may conflict with other strategies, such as establishing a free-growing crop of trees.

Some of the issues involved in the process of revegetation are discussed in the subsections that follow.

Figure28: In many regions, drill sites can be reclaimed by revegetation with local plant species after ground preparation (scarifying). © Noranda/Falconbridge

14.6.1 Revegetation Strategies and Techniques

A revegetation strategy depends upon the reclamation objectives. Alternatives to consider, and different techniques which can be used, are included in the sections that follow, and in the information below:

- To control surface erosion, use grass and legume seed mixes as the first choice, then shrub and hardwood species. Keep in mind, however, that grasses, particularly sod-forming species, may interfere with shrub and tree establishment on some sites.
- Use vegetation with ecological characteristics that are compatible with the long-term objectives. Learn about the potential of native grasses and legumes, by experimenting on sites that have low erosion potential. Remember, however, that experience with native grasses and legumes may be limited in the area, and they may be in fact more risky than agronomic seed mixes, where immediate erosion control is required. Consult with a specialist in the area for help in selecting native plants for use in rehabilitation programs.
- To restore and maintain soil structure, use grasses and legumes, especially in medium- and fine-textured soils.
- Consider using native shrub and tree species, to enhance the development of a soil profile which best maintains the local ecological balance. These can also be successfully interplanted with exotic species such as conifers, wattles, or eucalypts, but they are less effective than grasses and legumes for short-term erosion control and for rapid improvement in soil structure.
- Develop, or have an expert develop, site-specific requirements for seeding rates, planting densities, and species mixes. A more intensive approach to the reclamation work is often required than what is normally applied in agriculture.
- Consider using bioengineering techniques in situations of high sensitivity or risk.

When developing strategies for revegetation, it is important to consider other uses of the site and their possible effects on the program. For example, where wildlife populations are large, plan to control browsing of the site by creating access barriers until the vegetation is sustainably developed, or by delaying planting until other food sources are available.

Also, in areas where cattle are grazing, measures can be planned and implemented to prevent cattle from congregating on the reclaimed area, by minimizing use until tree seedlings are established, or by planting obstacles to protect seedlings. Local experience will often be the best source of innovative solutions to the problems associated with shared use of reclaimed areas by wildlife and cattle.

Above all, remain flexible. There are an almost unlimited number of possible strategies available, so be guided by the ecological considerations of the site, the analysis of the risk, and the ultimate objectives.

14.6.2 Species Selection

The species selected for revegetation the project area will depend upon the:

- Future land use
- Soil conditions
- Climate in the region

If the objective is to restore the native vegetation and fauna, then the species are already predetermined. If the soil conditions are substantially different after disturbance, then some exotic species may need to be introduced.

Species considered to be appropriate to the reclaimed area have similar growth forms to the original vegetation and thrive in areas with comparable:

- Soil types
- Drainage status
- Aspect
- Climate

A good practice is to search the area of the project locally for natural analogues to the area, and use them as models for site rehabilitation. Take care, however, to avoid introducing species that could become fire hazards, invade the surrounding areas of native vegetation, or become a weed for the local agricultural industry.

Be aware that "pretty" reclamation may not be the most desirable or most acceptable. A former coal mine in northwestern North America is a good example. The operator began reclamation in the 1960's and by the 1980's was very proud of its picturesque effort. Unfortunately, the local Dall sheep were also impressed and hunters simply had to hang out near the site to bag a sheep without an arduous climb, as in past years, into the nearby mountain range. The sheep population suffered significantly and the operator was forced to alter its reclamation procedures to eliminate this unnatural animal attraction.

Where the future land use is agriculture, then again the species selection for revegetation will be governed by what is generally used for pasture or crop in the area. Where a quick remedy is required for erosion control cover crops can be considered, but this must not be to the detriment of establishing an ecosystem based on returning the land to its previous balance.

The following subsections contain information on specific plant groups that can be considered for revegetation. It is very important to always seek expert advice on species selection before implementing any reclamation program.

14.6.2.1 Grasses and Legumes

Choosing the proper species for a particular situation requires that the characteristics of the species be matched with site conditions and reclamation objectives. Attributes that may affect the suitability of plants for a particular site and objective include:

- Root form
- Reproductive system
- Growth form
- Timing
- Adaptability

Choices may be very site-specific. For help in formulating the most appropriate seed mixes, consult experts who are familiar with the area.

Native plants, domesticated native plants, or introduced agronomic species can be used for reclamation. The seeding of agronomic grass and legume species is an established technique for erosion control in many parts of the world, and there is a very large selection of species to choose from. Seed mixes can be easily tailored to achieve particular effects to meet many revegetation objectives, such as:

- Restoring soil structure
- Enhancing site nutrient status
- Hastening “green-up”
- Producing forage

Native and domesticated grasses and legumes can be used in the same situations and applications as agronomic varieties; in many cases, they will be better suited for use on a particular area. Many native plants may be well-adapted to conditions of low nutrient status, and they are likely to reduce the potential adverse effects on biodiversity that may arise from seeding introduced plant cultivars.

Advantages of seeding grass and legumes for reclamation include:

- Seeding is inexpensive, fast, and easy
- Many different varieties are available for specific conditions or to meet a variety of objectives
- Seeding promptly after disturbance provides an almost continuous ground cover
- Dense root mats formed by some species are very favourable for stabilizing soil and developing soil structure
- Deep-rooted species are highly suitable for reducing soil moisture levels where slope stability or site wetness is a problem
- Some species establish rapidly and yet are short-lived, thereby reducing competition over the longer term
- Many species of grasses and legumes are widely adaptable
- Some native species can be used in many situations, and others (e.g., less palatable or low-growing species) can be developed for special uses

Disadvantages of seeding grasses and legumes for reclamation include:

- In warmer climates, seeded species may affect tree growth, by competing for moisture and nutrients

- In colder climates, seeded species may increase the risk of frost damage and snow-press damage to tree seedlings
- Many species currently used are not native or are used outside their native range, and may have adverse effects on biodiversity when used in forest, desert, or range ecosystems
- Where emergency revegetation is required, the effect of uncontrollable factors (e.g., weather, seed predation) needs to be considered
- Few nitrogen-fixing legumes can be grown in acid soils or at high elevation

14.6.2.2 Shrubs

Revegetation with native shrubs can be a valuable reclamation tool, particularly in highly sensitive areas such as recreation areas, alpine tundra, and grasslands. Native shrubs have not received a great deal of attention for reclamation in the past, but the infrastructure necessary to allow routine use of shrubs has been rapidly developing in recent years.

Commercial seed-pickers can be used to collect material from many areas, and several nurseries currently grow native species in a variety of container stock types. There are various methods that can be used to establish native shrubs, although they may often be browsed in some areas. Container stock can be hardy and can be planted in areas where seed retention and survival are a problem.

If a source is available, it may be possible to plant any species by direct seeding, or to establish them from rooted cuttings. For help in developing reclamation plans involving the use of shrubs, consult with ecology and soil specialists in the area.

Advantages of planting shrubs for reclamation include:

- Shrubs have deep, woody root systems that give mechanical support to slopes. When planted with grass, they can help to prevent sloughing of the shallow sod layer. The woody top growth also helps to stabilize rehabilitated areas by reducing surface wind velocity.
- Shrubs establish more quickly and easily than trees, and often grow on sites not suitable for hardwood trees.
- Available shrub species tend to be indigenous and better adapted than introduced grasses and legumes.
- Some species will fix nitrogen even in areas where legume success is unlikely.
- Shrubs may serve as nurse trees to a hardwood crop, providing a source of browse to draw animals away from seedlings and protecting seedlings from frost.
- Shrubs can improve soils by drying them out or by adding organic matter. Compared to grasses and legumes, these objectives may be achieved with fewer negative effects.
- Shrubs provide a good source of food and protective cover for wildlife.
- In some areas, shrubs may improve visual quality by screening other disturbed areas from view, thereby softening the aesthetic quality of those areas.

Disadvantages of planting shrubs for reclamation include:

- Ground cover is discontinuous and it may take many years to develop a continuous root mat. Planting shrubs is not the best choice for short-term erosion control.
- There is no immediate return on the cost of planting, though there may be later benefits.

- Shrubs will compete with other plant types, but in well-designed plantings there will be a net growth benefit to the area.
- Some shrub species may be severely checked by heavy browsing.

14.6.2.3 Trees

Much of the previous discussion on native shrubs applies to trees as well, including the recommendation to consult with experts before implementing the reclamation program. Investigations into mixed planting have indicated that, in certain situations, some species may confer some growth and performance advantages to the other components of a mixed planting program.

Advantages of planting trees for reclamation include:

- Many tree species may be natural pioneers of disturbed sites. They can establish easily, and produce large quantities of leaf litter, which helps rebuild the natural ecosystem, stimulate plant and microbial activity, and re-establish soil ecosystem functions. Their roots help improve the soil's physical and chemical properties.
- Some species grow fast, which helps "green-up" disturbed areas and enhance visual quality.
- A tree cover on rehabilitated areas may contribute to the achievement of biodiversity and wildlife habitat objectives.
- Tree cover on rehabilitated areas may contribute to the achievement of biodiversity and wildlife habitat objectives
- Depending on the stocking levels, hardwoods in particular may act as a nurse crop and improve plant growth, by moderating temperatures and protecting grasses and shrubs from browsing and wind
- Returns on planting cost may be achieved by replanting species that can be utilized as a sustainable commercial forestry industry

Disadvantages of planting trees for reclamation include:

- Above and below ground growth is often slow compared to that of some other types of vegetation.
- Forest floors and site-nutrient pools are restored more slowly than with other vegetation types.
- Root systems are coarse compared to those of some other types of vegetation. Such root systems are not the best for controlling erosion or restoring soil structure.
- Commercial planting densities are often too low to provide optimum reclamation effects (e.g., erosion control, nutrient capture).

14.6.2.4 Natural Regrowth

The word "regrowth" can be defined as native trees and shrubs that re-establish on land previously cleared for exploration or mining activity, and can be considered as the natural regeneration of woody vegetation. The term "ground cover" is used to describe a wide variety of soil surface cover features such as grasses, herbs, and forbs (collectively known as vascular plants).

Ground cover can also include persistent plant litter (e.g., bark, logs), ephemeral or non-persistent litter derived from the detachment and breakdown of plant material, stones, animal dung, and non-vascular plants (e.g., mosses, lichens, liverworts, other microbiota).

The subsections that follow will help in planning and managing regrowth programs.

Figure 49: In parts of Australia, drill sites and access roads can be ripped or furrowed to expedite rapid regeneration of vegetation. In forested terrain elsewhere, a similar technique is called scarifying. © Mithril Resources.

Figure 50: In this more detailed image, note that some vegetation remains for faster overall regeneration. © Mithril Resources.

14.6.2.5 Regrowth Planning

When the balanced ecosystem of the exploration site is disturbed, the native plant regeneration process can dramatically alter. Therefore, it is vital to plan and manage vegetation clearing to ensure the longer-term viability of the land. An overall regrowth control plan is needed before the initial clearing is carried out, to ensure that the land remains useable, and that land which is not likely to benefit from clearing is not disturbed.

Regrowth can rapidly reduce land productivity to less than what it was before it was cleared (e.g., by the invasion of exotic weed species). In some cases, it can even increase soil erosion because of poor soil binding. In fact, in some plant communities, excessive regrowth of young plants (both native and exotic species) may be stimulated by land disturbance.

The regrowth following clearing usually comes from:

- Lignotuber
- Root sucker
- Seed

Some types of vegetation are more prone to regrowth than others. Seeds may quickly germinate soon after clearing in response to an increase in available light, but seeds of some species can remain dormant for long periods of time until conditions are more favourable. Native species in some areas may quickly regrow after clearing, but they are usually not invasive, and they tend to only recolonize the area on which they were originally growing.

Not all regrowth is detrimental, however, and provided the vegetation type is native to the area, it can be extremely advantageous to a reclamation program. Using natural regrowth can contribute to the reestablishment of the ecological balance in the area, by quickly returning the physical and chemical characteristics required by the soil and vegetation. In some cases, regrowth itself may be sufficient to rehabilitate areas back to their original environmental state.

Other factors to consider:

- Seasonal and soil moisture conditions can have a big effect on root suckering and seedling regrowth. Warm temperatures and optimum soil moisture will stimulate plant growth.
- Clearing methods can have differing results, depending on the conditions of the site both before and after clearing.

14.6.2.6 Regrowth Management

The regrowth of woody plants after the clearing of the exploration site may cause problems for the continued management of the reclamation plan. Although tree regrowth is often detrimental, its complete removal is not encouraged.

In many parts of the world, the evidence for degradation from over-clearing is obvious, and often results in:

- Increased salinity
- Soil erosion
- Loss of biodiversity
- Changes in microclimate
- Ultimate loss of land use

Through careful management and selective control, mining exploration companies can avoid such problems, and learn how to work with nature to keep the land sustainable for the future. Should the reclamation plan not include natural regrowth, or the program require only restricted regrowth, then some common methods of control to consider are set out below.

Blade Ploughing
This is often used on very thick regrowth before it is very tall. A large single-tined plough is pulled below the main tree root mass, cutting off sinker roots and lifting the suckers.

Conventional Ploughing
This can be used as part of a planting program after clearing. It may take several years to control regrowth fully by this method. It is not particularly beneficial, except when used to rehabilitate agricultural land. Contour or otherwise protect land susceptible to erosion.

Chemical Treatment
A variety of herbicides can be used to effectively control regrowth. Broad-scale application is often difficult or costly, but for small areas overall spraying, basal bark application, or stem injection techniques may be suitable, depending upon the size and type of regrowth present in the area.

Note that most chemical applications (e.g., aerial application) should adhere to local legal requirements, and only be used by registered spray applicators. Careful planning is essential before using any pesticide or herbicide.

Fire
Fire is a major environmental factor in many areas. Hot fires often kill young seedlings quite effectively, but adequate fuel, in the form of grass or fallen timber, is required. If used sensibly, fire is cheap and effective, but it is less effective on sucker regrowth. Careful use of fire can also benefit biodiversity and restoration in some plant communities. Note that a permit may be required under local fire control regulations to burn vegetation.

Competing Vegetation
An effective long-term control measure may involve the introduction of competing vegetation immediately after initial clearing. This can help reduce the successful establishment of tree seedlings. Suckers may not be as effectively controlled by this method because of their greater ability to establish quickly.

Introducing revegetation immediately after clearing or disturbing soil also has the advantage of preventing the invasion of exotic weeds. These weeds may be capable of forming dense thickets that can cover large areas quickly.

14.6.3 Seeding

Sowing seed is an economical and reliable method for establishing some vegetation species. It results in a more random distribution of plants than planting seedlings and leads to more natural looking vegetation. The species best established from sown seed are those that produce large numbers of easily collected viable seeds and those that have a high germination and survival rate in the field. When seed is being considered for the establishment of vegetation at the exploration site, take into account the specific goals for the established plants.

These can include:

- Erosion control

- Weed control
- Improving soil productivity (e.g., nitrogen fixation, organic matter, soil structure)
- Displacement of unwanted vegetation
- Increasing forage production
- Aesthetics

The specific goals selected will in part determine which species of plants to establish from seed in the area. The subsections that follow provide useful information for implementing a seeding program.

Figure 51: Reseeding an abandoned airstrip in the sub-Arctic with local hardy plants. © BHPBilliton

14.6.3.1 Seed Mixes

When planning the revegetation method, a mix of seeds can generally be used as a way to include a variety of plant species that take advantage of different site conditions, the required growth forms, establishment rates, and persistence. A number of plant species can also be considered, depending upon which characteristics are beneficial to the program.

These characteristics can include:

- Rooting profile
- Nitrogen-fixing ability
- Growth habit (creeping, mat forming, tufted, or bunch plants)
- Establishment characteristics (slow or fast)
- Ability of the plant to occupy the site, persistence
- Height
- Forage quality and quantity

Legumes are sometimes included for nitrogen fixation and for their aesthetic value. Because they generally require more moisture than grasses, however, it is necessary to reduce their component in mixes for dry sites.

In addition, the supply of seed and its cost are important practical considerations in the development of all seed mixes.

The addition of tree seeds to grass/legume mixes is not usually recommended for best results. Good practice is to consult an erosion control specialist, agrologist, or botanist who is familiar with the area.

14.6.3.2 Seed Application Methods

Seed can be applied by several methods, including dry seeding, wet broadcast seeding, or hydroseeding. The local soil materials, slope, and climate usually will determine which is the most suitable method to use.

14.6.3.3 Dry Seeding

There are 4 methods of dry seeding:

1. Hand broadcast. Flat or gently sloping areas (<50%) can be seeded by hand or by a rotary type "belly grinder" seeder; both are generally inexpensive and simple to use.
2. Motor-driven cyclones. The speed of broadcast seeding can be improved by using a motorized seeder (e.g., Herd seeder, cyclone seeder).
3. Air blowers. An air compressor can be used to blow seed or fertilizer up to 10 m. This method is best suited for roadsides, because the equipment requires vehicle transport. Approximately 2-5 km of road can be seeded per hour using this method. Coated seed is recommended for improved ballistics.
4. Helicopter. Inaccessible areas with gentle to moderate slopes can be dry seeded, using a spreader bucket slung from a helicopter. If they are not too steep and not easily hand seeded, impassable and/or abandoned roads, with fill material pulled upslope onto the road, are suitable candidates.

Wet Broadcast Seeding

This system mixes dry grass and legume seeds with water, and immediately discharges it onto the area to be seeded. Use this system where dry seeding would otherwise be prescribed. It offers the following advantages over dry seeding:

- The water jet carries seed further
- A larger surface area can be treated per unit of time
- Better control of seed dispersal is possible
- Seed germination is accelerated and enhanced

This technique is most useful for revegetation disturbed areas with limited access.

Hydroseeding (Hydraulic Seeding)

This method can be used by applying a water slurry of seed, fertilizer, and a soil-binding agent (tackifier), with or without mulch. Use hydroseeding on open slopes greater than 60%, where tacking the seed to the slope is necessary.
There are 2 methods of hydroseeding:

- Ground-based: With this type of hydroseeding, truck-mounted equipment is used to apply the slurry on roadsides and accessible areas. The equipment consists of a mixing tank with mechanical or hydraulic agitation, and a volume pump.
- Helicopter: For inaccessible areas, a truck-mounted mixing tank is used to fill a spreader bucket slung beneath a helicopter. Helicopter applications can add a suspension agent, mulch, or both to the slurry, to prevent settling during the trip from the staging area to the seeding site. Aerial hydroseeding is suited primarily to inaccessible areas, such as drill sites previously accessed by helicopter.

Seedbed Preparation

Slopes must be mechanically stable for the long-term success of seeding. It may, however, be necessary to seed unstable slopes as an interim measure.

A good seedbed has small cracks and discontinuities that trap seed, providing good contact between the seed and the soil. This improves germination, because it helps to prevent the seed from drying out. Large clods and very rough surfaces do not make good seedbeds, because the clods dry out before the seeds germinate. Also, the seed tends to collect in the lowest points, resulting in very patchy distribution.

Seedbed conditions after disturbance are probably worst on compacted, smooth soil surfaces because they deteriorate with time. Rainfall will cause a crusting of the soil at the surface, and the infilling of small cracks and pores that would otherwise trap seed. Seed as soon as possible after disturbance, and consider using a hand rake or tiller to prepare the site if only small areas need to be treated. Consider the size of the seed as a guide to the degree of surface roughness required.

14.6.4 Cuttings, Seedlings and Transplanting

It may be possible to propagate shrubs and trees from seeds, cuttings, divisions, or tissue culture and then grow them in containers in a nursery, to plant out at a later date. The planting of nursery-raised cuttings and seedlings is more appropriate when it is not possible to establish the particular species in suitable numbers through seeding or topsoil return. It is usually more economical, however, to establish plants by direct seeding than by planting seedlings.

Planting seedlings may also be appropriate when the reclamation objective requires a systematic layout of plants, as in the case of reforestation. Planting seedlings on a regular basis requires a reliable supplier of consistent quality seedlings or an on-site nursery. Select shrubs and tree species based on the reclamation goals and site conditions, and always acclimatize seedlings before planting them in the field.

A mixture of plants will increase the chances of success, as first-year survival rates can often be low for seedlings and cuttings. A survival rate of 50% is considered normal for unrooted cuttings, while the survival of rooted cuttings and seedlings may be as high as 90%. In general, shrubs used in reclamation work should be pioneer species, specifically adapted to invading disturbed areas. These pioneer species can tolerate low moisture and nutrient conditions, and can withstand temperature extremes that often occur on degraded soils with minimal vegetation cover.

Suitable species for the area can be identified by looking at previously disturbed sites close to the exploration area. Some considerations for transplanting include:

- Shrubs used in reclamation work should be pioneer species, specifically adapted to invading disturbed areas. These pioneer species can tolerate low moisture and nutrient conditions, and can withstand temperature extremes that often occur on degraded soils with minimal vegetation cover. You can identify suitable species for your area by looking at previously disturbed sites close to your exploration area.

- Do not transplant shrubs between areas where the elevation differs by more than about 170 m.
- Aspect also has a considerable influence on the probability of success, especially at higher elevations. In the Northern Hemisphere, shrubs grown on sites with a north aspect are more adapted to cool, moist conditions and most likely would not grow well on dry, south-facing slopes. Similarly, shrubs grown on southern aspects may do poorly on north-facing slopes. The reverse applies in the Southern Hemisphere.
- The ease of propagation of cuttings and seedlings may limit the choice of species.
- Select species with the desired growth form to meet objectives, such as short versus tall form, browse-resistant, or deep-rooting species.

Grasses and legumes are usually best developed from seed, and do not generally propagate well from cuttings, cultures, or plant division. Some species, however, will grow from root tubers or root stock. Transplanting sods or grass mats may be an option to consider, but the cost and availability of suitable material will restrict this option to very small areas, or to specialized cases requiring the immediate establishment of ground cover.

The use of direct transplanting or habitat transfer can also be considered for species that cannot be established by other means. This method involves transferring slices of soil and vegetation intact from established vegetated areas and transplanting them on the disturbed area. The direct transfer of large shrubs and trees is a specialized operation and it is a good idea to consult with professionals in this area. It is, however, an expensive option and its success is greatly influenced by climatic conditions.

.14.6.5 Bioengineering Techniques

Bioengineering in reclamation refers to the use of living plants to create structures, usually to control erosion, provide protection, or to stabilize slopes. Bioengineering techniques involve the very intensive use of relatively large pieces of living material in such quantities that they help to provide slope stability and shelter, even before they begin to grow. One action can achieve the benefits of revegetation and slope stabilization, as the living material grows.

Bioengineering can be used to stabilize existing slopes or to help reshape slopes to more stable forms. Small terraces, for example, can be created to trap sediments and to dissipate the energy of running water.

Bioengineering techniques can be used where:

- Slopes are very steep and a high seed loss is likely
- There is high risk of damage to plants or property, and there is significant public concern

The major categories of bioengineering techniques include:

- Live staking. With this technique, individual cuttings are inserted, driven, or buried in a random, grid, or linear pattern to immediately stabilize eroding or slumping slopes.
- Wattles (sticks interwoven into fences) and fascines (bundles of sticks). This technique involves staking or burying fences or bundles of interwoven live branches in rows or shallow trenches, either parallel or diagonal to the slope contours, to create relatively large structures to trap sediments, to slow water movement, and ultimately to revegetate slopes.

- Cordons, hedges, and brush layers. Using this technique, terraces or trenches are constructed, either parallel or diagonal to the slope contours, for hedge-like plantings of live cuttings or rooted trees or shrubs, to stabilize loose slopes and provide shelter from wind and rain.

The advantages of using bioengineering techniques for reclamation are:

- They provide immediate results for erosion control, windbreak, and slope stabilization, which is important for sensitive or risky situations.
- Their use is very flexible. Many effects can be achieved by varying the techniques or design of the structure.
- They can be successful where less intensive approaches are likely to fail (e.g., on steep slopes where surficial materials are unstable).

The disadvantages of using bioengineering techniques for reclamation are:

- They are very labouring intensive and expensive, and at best can be used only in critical areas.
- They can only be implemented where there is an available source of suitable material.
- Specialized knowledge is required to implement the techniques. Relatively few people are familiar with them, compared to other revegetation techniques.

14.6.6 Documentation

The original condition of the land is often the benchmark by which the success or failure of a reclamation program is judged. It is thus in the interest of both the explorationist and the regulating authorities to have an accurate and objective record of the pre-existing conditions at the exploration site. A useful approach is to record, with photographs, the pre-existing condition of the site prior to disturbance, and subsequently to maintain a photographic record during exploration activity, which will document the level of disturbance and efforts to reclaim the sites.
It is simply not sufficient to compare the exploration site reclamation against the condition or productivity of the land surrounding the project area, as there may be good reasons why the lease or permit area, or parts of it, were significantly better or worse than those lands adjoining. Environmental information should therefore form part of the baseline data and should be collected prior to exploration activity. More detailed investigations may, however, be required at a later date as the project develops.

Prepare the site plans during the collection of baseline data early on in the exploration activity. To maximize the level of information, satellite imagery interpretation or aerial photography can be used, to form the base maps from which more detailed information can be followed up by ground verification. Quite often, maps which can be used as base maps are available - for example, at a scale of perhaps 1:50,000 or 1:100,000 - from government agencies (e.g., mapping authorities, soil conservation, agricultural and national parks agencies). These can provide a valuable base from which to collect more detailed data from on-site surveys.

Mapping scales will depend to some extent on the size of the project, the planned activities and the degree to which the various land characteristics are disturbed. Generally, mapping at a scale of 1:20,000 is adequate for a preliminary analysis of the site, but this may change depending upon the planned scale of disturbance. For reclamation planning, more detailed mapping (e.g., at an approximate scale of 1:5,000) is usually recommended for topography and drainage, topsoil stripping depths and for vegetation distribution.

As part of the environmental baseline documentation, it is suggested that information be collected on the following subjects.

Land Ownership

This information may include property boundaries, locations of roads and other service corridors, and can be enhanced by collecting details on current land uses, either on the plan itself, or in a separate report. If possible, identify the location and extent of significant areas of land degradation (e.g., due to severe soil erosion, salination, weed invasion) on the map if possible. Similarly, particularly valuable attributes can be recorded (e.g., areas of undisturbed native vegetation, wildlife habitats and corridors, areas of prime agricultural land).

Where prime agricultural land is to be disturbed and subsequently reinstated, it is worthwhile to gather some information on the local agricultural productivity. Regional data on historical production levels from a range of local agricultural activities can often be obtained from agriculture departments.

Topography

Prepare a contour plan that clearly shows the drainage system, and the complete details of ephemeral and permanent watercourses. This will provide the key to designing a drainage system for reshaped land that is compatible with the surrounding drainage network.

Contour spacing will depend on the degree of relief and may range from 1 m or even 0.5 m spacing for flat areas, to 10 m or more for very rugged terrain. Special features such as cliffs, wetlands, and major catchment boundaries should be marked on the plan. In some situations, an additional plan showing slope classes at 5° (11%) intervals can be useful to plan a future landform that will blend visually with its surroundings.

Land Capability

Maps of land capability are useful in areas where the land will be returned to agricultural use. This system of classification is commonly used by soil conservation, agricultural, and planning agencies. It allocates land to one of a number of classes, according to its ability to support sustainable agricultural and grazing activities at various intensities. It takes into account a number of factors (e.g., slope, soil type, vegetation, climate), together with the effects of past land use practices, soil erosion, drainage, and salination.

If similar land capabilities are to be restored after exploration, then reshaped landforms will need to be compatible with the proposed capability on each part of the site. Land capability mapping is a specialized activity, and should only be undertaken by a person who is competent in the use of the classification system, and who has an intimate knowledge of the local soils, climate, and land use in the area.

Soils

Survey soils by examining profile exposures in roadside cuttings, erosion gullies, etc., and supplement this by drilling core to a sufficient depth to penetrate subsoil or weathered parent rock. The objective is to clearly establish the boundaries between the different soil types, and to gather data on the depth of material suitable for stripping and for subsequent use in reclamation.

In many situations there is a strong correlation between soil type boundaries and vegetation distribution. Where the aim is to restore predisturbance vegetation communities, it may be very important to re-establish them on their matching soil types. There is often a close relationship between soil types and landform or topographic position, that can be used to advantage in locating the boundaries between different soil types. For example, ridge crests and steep slopes are frequently covered by thin, stony, or light, sandy soils, whereas stream flats and floodplains often consist of deep, fertile, alluvial soils. It is important to check, however, for the possible effects of waterlogging and salination, which may negate the value of the soil for topdressing.

Where the parent rock materials are fairly uniform, the boundaries between soil types often roughly follow the contour - a feature that can be useful for quickly locating soil type boundaries during field surveys. Collect representative samples of topsoils and subsoils likely to be used for topdressing, and have them analyzed for a range of physical and chemical characteristics (e.g., clay dispersibility, macro- and microelements, cation exchange capacity). Guidelines on survey and sampling procedures and analytical methods for a range of parameters are usually available from soil conservation and agriculture departments.

Vegetation

Surveys of vegetation are a subject in their own right. They are mentioned here because it may be necessary, in some situations, to re-establish habitat corridors and vegetation along streams. When mapping vegetation groups, take account of their topographic position, associated soil types, and moisture characteristics, so that similar microenvironments can be created during reshaping and topsoil replacement. Even in areas dominated by agriculture, remnant stands of trees along ridgelines and watercourses may provide essential wildlife habitats and corridors. Therefore, new landform designs should link corridors on adjacent lands, as far as possible.

Figure 52: Hand-dug pits can be considered in the same manner as trenches for purposes of EES. Reclamation is essential (after full documentation) for both environmental and safety reasons. © Iamgold.

Figure 53: This before and after shot from eastern North America indicates how well trenches can be reclaimed. After a few short years, there will be very little evidence of this trench.© Noranda/Falconbridge.

14.7 Bond Requirements

Reclamation bonding is meant to serve as an "insurance policy" against pollution problems. It is a cache of money that may be required before work can begin, which can be used for cleanup at the end of the program.

If a bond must be posted for a program, it is important to ensure that it has clear conditions of release. Explorationists then need to work diligently with the bondholder, to ensure that the requirements of the bond are met, and that the bond is released in a timely fashion upon satisfactory completion of all reclamation work.

Although bonding is more commonly included as part of the regulatory regime encountered during mine development, there is now considerable interest, particularly from environmental groups, in introducing bonding requirements earlier in a project's development. This means that, at a later date, a company may be required to lodge some type of surety during the exploration program, to ensure that proper reclamation of land disturbance takes place, regardless of the outcome of that activity.

There is also growing interest by environmental groups and government agencies in the establishment of a levy or tax on exploration activity. This could be used to fund the reclamation of lands that historically have been disturbed by mining and exploration.

Reclamation costs can vary significantly from site to site, and can range from less than US$2,400/ha to more than US$72,000/ha. The higher costs usually occur at properties that are in remote locations or may have significant environmental concerns.

Generally the main guidelines for bonding, as issued by many regulatory bodies, are as follows:

- Bonds will be required as a part of the operating permit or lease, for the purpose of assuring completion of a reclamation and closure plan, and for any other requirements of any other laws and regulations relating to any permit conditions.
- Governmental agencies will determine and set the amount of financial assurance. They will derive their estimate from only verifiable sources, and will take into consideration all costs in determining the bond amounts. This will include adequate funding for interim reclamation and closure operations, as well as for indirect and overhead costs, and will take account of the cost of reclamation over the project life.

For financial assurance only, the following forms are usually accepted:

- Cash
- Surety bonds
- Letters of credit

Limited forms of other financial assurance mechanisms that are readily liquid (e.g., can be assumed as cash, in the event that reclamation and closure by the agencies becomes necessary) may also be accepted. A corporate guarantee or self-bonding will rarely be accepted as financial assurance.

To monitor performance, regulatory agency work includes:

- Conducting on-site inspections of existing and new operations at least yearly (and more frequently as necessary), to ensure compliance with the terms of the operating permit and the approved reclamation and closure plan
- Reviewing the bond amount and adjust the bond as necessary to reflect the actual current conditions, and reclamation and closure requirements
- Establishing closure and post-closure performance criteria to ensure compliance with applicable water and air quality standards
- Establishing the formation and means to support an emergency response and reclamation action

These agencies will cause the bond to be forfeited if the:

- Reclamation and closure activities are not initiated and completed as required
- Surety provider refuses or fails to perform the work
- Company is unable to maintain the financial surety

Facilitate full and unrestricted public participation in the process of establishing reclamation and closure plans and bond amounts, and as a part of bond release.

Some or none of these concepts may apply currently in the planned exploration area. Nevertheless, be prepared to accept these, should the regulatory framework change or be introduced in the exploration area.

14.8 Monitoring Inspections

It is essential to monitor the success of the reclamation program and to be prepared to rework any areas that are not developing adequately. Define success criteria, and ensure that they are agreed upon by all stakeholders during the development of the reclamation and closure plan.

Factors to consider including in success criteria are:

- Physical. The area's stability, resistance to erosion, and reestablishment of drainage.
- Biological. These factors include species enrichment, plant density, canopy cover, seed production, fauna return, weed control, productivity, establishment of nutrient cycles, and water quality standards for drainage water.
- Political. These include public safety issues, regulatory requirements, stakeholder satisfaction, and aesthetic value.

Design monitoring techniques to provide statistically valid results, with the desired order of accuracy. The sampling intensity will usually have to be a compromise between the required level of precision of the collected data, and the cost of collecting these data.

Be prepared to monitor and manage reclaimed areas after reclamation. Reclamation success is often compromised by the invasion of feral and stock animals, weeds, or human activities. Consequently, self-sustaining conditions may take many years to reach and may require closely monitoring the reclamation area.

As a result, it may be necessary to:

- Replant failed or unsatisfactory areas
- Repair any erosion problems
- Introduce fire management
- Control pest and weed outbreaks
- Control feral and native animal populations
- Refertilize slow or poorly established vegetation
- Water plants in drier areas, especially during the establishment phase
- Apply lime or gypsum to control pH and improve soil structure

Reclamation is an essential part of developing mineral resources, in accordance with the principles of ecologically sustainable development. Ecosystem restoration is a relatively new science, even though humans have been disturbing the land for many centuries.

The mining industry is developing the expertise to reassemble species into communities that have a chance to grow, develop, and rebuild the local biodiversity. A company can contribute to this by paying careful attention to every aspect of reclamation and revegetation programs, from the initial planning through to the maintenance of areas into the future.