



Australian Government

Department of Industry  
Tourism and Resources

# MINE REHABILITATION

LEADING PRACTICE SUSTAINABLE  
DEVELOPMENT PROGRAM FOR  
THE MINING INDUSTRY



SOCIAL  
ECONOMIC  
ENVIRONMENTAL



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DEVELOPMENT PROGRAM FOR  
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OCTOBER 2006

## **Disclaimer**

Leading Practice Sustainable Development Program for the Mining Industry

This publication has been developed by a Working Group of experts, industry, and government and non-government representatives. The effort of the members of the Working Group is gratefully acknowledged.

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Cover image: Rehabilitation at Xstrata Coal's New Wallsend Colliery located in the Newcastle Coalfield, New South Wales

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## FOREWORD

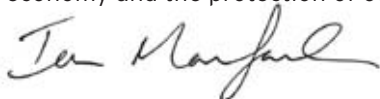
The Australian mining industry is well aligned to the global pursuit of sustainable development. A commitment to leading practice sustainable development is critical for a mining company to gain and maintain its 'social licence to operate' in the community.

The handbooks in the Leading Practice Sustainable Development in Mining series integrate environmental, economic and social aspects through all phases of mineral production from exploration through construction, operation and mine site closure. The concept of leading practice is simply the best way of doing things at a given site. As new challenges emerge and new solutions are developed, or better solutions are devised for existing issues, it is important that leading practice be flexible and innovative in developing solutions that match site-specific requirements. Although there are underpinning principles, leading practice is as much about approach and attitude as it is about a fixed set of practices or a particular technology. Leading practice also involves the concept of 'adaptive management', a process of constant review and 'learning by doing' through applying the best of scientific principles.

The International Council on Mining and Metals (ICMM) definition of sustainable development for the mining and metals sector means that investments should be technically appropriate, environmentally sound, financially profitable and socially responsible. *Enduring Value - the Australian Minerals Industry Framework for Sustainable Development* provides guidance for operational level implementation of the ICMM Principles and elements by the Australian mining industry.

A range of organisations have been represented on the steering committee and working groups, indicative of the diversity of interest in mining industry leading practice. These organisations include the Department of Industry, Tourism and Resources; the Department of the Environment and Heritage; the Department of Industry and Resources (Western Australia); the Department of Natural Resources and Mines (Queensland); the Department of Primary Industries (Victoria); the Minerals Council of Australia; the Australian Centre for Minerals Extension and Research, the university sector and representatives from mining companies, the technical research sector, mining, environmental and social consultants; and non-government organisations. These groups worked together to collect and present information on a variety of topics that illustrate and explain leading practice sustainable development in Australia's mining industry.

The resulting publications are designed to assist all sectors of the mining industry to reduce the negative impacts of minerals production on the community and the environment by following the principles of leading practice sustainable development. They are an investment in the sustainability of a very important sector of our economy and the protection of our natural heritage.



**The Hon Ian Macfarlane MP**  
Minister for Industry, Tourism and Resources





# 1.0 INTRODUCTION

This handbook addresses mine rehabilitation, one of the themes in the Leading Practice Sustainable Development Program. The program aims to identify key issues affecting sustainable development in the mining industry and provide information and case studies that illustrate a more sustainable basis for the industry. There are a number of other themed handbooks in the series, which aim to complement this handbook. The exchange of information between all participants in the mining industry is important for promoting leading practice and this program aims to improve that information exchange.

The leading practice handbooks are relevant to all stages of a mine's life exploration, feasibility, design, construction, operation and closure and to all facets of an operation. While the principles guiding leading practice are often generic, they can be used to support site-specific sustainability planning.

The primary audience for this handbook is management at the operational level, the pivotal level for implementing leading practice arrangements at mining operations. In addition, people with an interest in leading practice in the mining industry including environmental officers, mining consultants, governments and regulators, non-government organisations, mine communities, and students will find this handbook relevant. It has been written to encourage these people to play a critical role in continuously improving the mining industry's sustainable development performance.

This handbook outlines the principles and leading practices of mine rehabilitation, with emphasis on land form design and revegetation. It shows readers how to use current and emerging technologies and practices more efficiently. The principles described should apply to any land disturbed by mining. Following the operational sequence in mining operations such as consultation, planning, operations and completion, each chapter focuses on the processes and issues relevant to the site over its life span. Particular emphasis is given to the restoration of natural ecosystems, especially the re-establishment of native flora.

Topics covered include rehabilitation objectives, soil handling, earthworks, revegetation, soil nutrients, fauna return, maintenance, success criteria and monitoring. Managers with responsibility for rehabilitation should be able to adapt this information to their own particular situations when planning a rehabilitation strategy.

Rehabilitation is the process used to repair the impacts of mining on the environment. The long-term objectives of rehabilitation can vary from simply converting an area to a safe and stable condition, to restoring the pre-mining conditions as closely as possible to support the future sustainability of the site.

Rehabilitation normally comprises the following:

- developing designs for appropriate landforms for the mine site
- creating landforms that will behave and evolve in a predictable manner, according to the design principles established
- establishing appropriate sustainable ecosystems.

Landform design for rehabilitation requires a holistic view of mining operations, where each operational stage and each component of the mine is part of a plan which considers the full life cycle of a mine such as planning operations and final end use of the site. This plan needs to be flexible to accommodate changes in method and technology.

Maximising planning reduces site disturbance and ensures that material such as waste rock is close to its final location. The emphasis is on gaining and analysing as much information as possible about the site. Such research has two main uses it provides baseline data for mine planning and essential information for the rehabilitation and closure phase, when the site is being restored to an agreed post-mining use.

Key factors that need to be considered in pre-mining studies include legal requirements, climate, topography, soils and community views. Community views are clearly most important in deciding the final land use as they are the most likely site users. Their knowledge and expertise can also be invaluable in understanding aspects of the site.

The post-mining land use for an area should be defined in consultation with relevant interest groups including government departments, local government councils, non-government organisations, Traditional Owners and private landholders.

Understanding the site, including its drainage characteristics, is also required when designing and siting components of the mine operation. By transferring this information to mining software, the mine planners have detailed computer modelling of the original site and its drainage patterns to make decisions about restoration or alteration in its final design.

Like all computer-related technology, developments occur and become outdated quickly. Therefore, the principles involved in digitising and analysing the data are more important than the specific software packages used. End uses for the final void resulting from mining operations also require consideration and planning. Backfilling may be uneconomic in some operations but, in others, planning might avert creating any void. Safety is also crucial and creative design in conjunction with substantial obstacles and warnings are needed.

## 2.0 SUSTAINABLE DEVELOPMENT AND MINE REHABILITATION

Poorly rehabilitated mines provide a difficult legacy issue for governments, communities and companies, and ultimately tarnish the reputation of the mining industry as a whole. Increasingly, as access to resources becomes tied to industry's reputation, effective closure processes and satisfactory mine rehabilitation become critical to a company's ability to develop new projects. Poor planning invariably increases the costs of rehabilitation and mine closure and decrease overall profitability. Taking a more integrated approach to mine rehabilitation, and doing it progressively, can achieve effective mine rehabilitation. A range of sustainable development policy frameworks have been developed by industry and other organisations that are now driving improved practice.

To provide a framework for articulating and implementing the industry's commitment to sustainable development, the Minerals Council of Australia has developed *Enduring Value - The Australian Minerals Industry Framework for Sustainable Development*. Enduring Value is specifically aimed at supporting companies to go beyond compliance to maintain and enhance their social licence to operate.

**Table 1: Enduring Value Principle/Element/Guidance**

ICMM Principle/Guidance Element	Description
<b>Principle 6</b>	<b>Seek continual improvement of our environmental performance</b>
<b>Element 6.3</b>	Rehabilitate land disturbed or occupied by operations in accordance with appropriate post-mining land uses.
<b>Guidance</b>	Consult relevant stakeholders and develop a closure plan that clearly defines the post-closure land use.
	Where appropriate, rehabilitate progressively over the life of the operation. Monitor success criteria agreed with relevant stakeholders. Report performances.
	Undertake and support research into land and water rehabilitation practices
	Use appropriate technologies to reduce negative environmental impacts and improve site rehabilitation techniques.
	Manage and, where appropriate, rehabilitate historical disturbances to an appropriate standard (see elements 4.1, 6.3, .6.4, 7.1, 7.3, 9.1, 10.3).

## **2.1 Sustainable development: environmental aspects**

It should not be assumed that the objective of all rehabilitation is some form of natural ecosystem approximating what existed prior to mining. In remote areas of Australia, a return of the mine site to a stable natural ecosystem is often the preferred option. If successful, this will provide a low-maintenance final land use, which seeks to control the release of potential pollution from the site.

In more densely populated areas of Australia (such as agricultural areas or sites close to population centres) a greater range of land-use options are available. Where components of the mine site have the potential to be used for agriculture or community-based activities, there will be a need for ongoing management. It is important to establish at an early stage the long-term capacity of the local community, its local council and community groups to undertake such activities. Without a long-term commitment and adequate resources, managed rehabilitation programs may ultimately fail.

### **2.1.1 Regulatory requirements**

Regulatory requirements place real constraints on options for rehabilitation. These constraints may arise in the form of regional land-use plans, which limit the types of final land-use which may be implemented. If an area is designated as a water catchment, then there will be requirements to return the site to a state compatible with this objective. This may preclude intensive farming due to the potential for pesticides or fertilisers to enter and pollute local waterways. If the site is surrounded by natural ecosystems, the introduction of intensive fish farming may pose a threat to native fish species in surrounding streams.

Regulatory conditions for rehabilitation can also be set as part of the specific permitting conditions for the approval of the mining operation. In some instances there will be a standard set of conditions applied to the project, but increasingly there is the opportunity for public input to the setting of these conditions. This can provide an early opportunity for community engagement to the mutual benefit of the project, the regulators and the community.

### **2.1.2 Physical constraints**

The physical attributes of a site place ultimate constraints on what can be achieved in a rehabilitation program. It may not be possible to re-establish some vegetation types, such as rainforest and wet sclerophyll forest, if the site lacks some of the required characteristics (such as rainfall and warmth). This could be due to the normal climatic regime of the site, processes such as climate change or the direct result of mining activity. It is essential to determine the physical constraints as early as possible in the consultation process in order to manage stakeholder expectations.

Some of the key physical constraints for consideration during consultation are included in Table 2.



**Table 2: Key physical constraints**

**Climate:** The climatic regime is the single most important factor to consider when developing options for mine rehabilitation. If the ultimate objective is to achieve a stable landscape it must be consistent with prevailing climatic conditions and consideration given to potential climate changes. Rainfall and temperature place real constraints on what can be achieved at the site.

**Size:** The size of the site has an impact on the options available. The shape of the site will also be a factor, particularly when considering issues where there is a strong edge effect, like colonisation by native plant and animal species, and weed invasion.

**Soil/rock types:** Soil type (clay, loam, sand), physical/chemical properties (pH, dispersive/non-dispersive clays) and the availability of nutrients are key determining factors in what vegetation the site will support. Management practices such as the application of soil amendments and fertilisers, and the retention of topsoil for use in later rehabilitation, can mitigate some constraints, but it may take decades for essential nutrient cycles to re-establish.

## 2.2 Sustainable development: social aspects

Mining companies in Australia have made a commitment to the social and economic development of the communities in which they operate. This entails a commitment to minimise the adverse impacts of mining on neighbouring communities, and also raises the issue of how to maintain or improve the wellbeing and social sustainability of affected communities.

### 2.2.1 Community engagement

Arriving at an agreed final land use for rehabilitated mine sites involves the careful balancing of competing demands from regulators, local residents and the wider community. More detailed advice on this subject can be obtained from the Mine Closure and Completion handbook in this series. The aim of community and engagement and consultation on the final land use is to arrive at an agreed set of objectives for the site that will allow the company to relinquish the site in a manner that meets regulatory requirements and satisfies community expectations. Progressive rehabilitation is the life-of-mine process that enables final land use objectives to be achieved.

The Leading Practice handbook in this series entitled: *Community Engagement and Development* provides further information and case studies on the best practice for effective community engagement and community development programs.

The rehabilitation options selected for the site need to be compatible and ideally complementary with surrounding land uses. Particular attention should be given to any opportunities to engage in or provide connecting habitat between remnant vegetation patches. There is also the opportunity to establish a broader regional rehabilitation plan, which takes into account the surrounding land-use activities. The sharing of expertise and the coordination of key activities can result in a significantly increased community benefit.

Several jurisdictions engage in landscape-level biodiversity planning, such as the regional biodiversity plans being implemented in New South Wales. Planning at this level is an effective way to manage issues such as wildlife corridors, determination of environmental water allocations and the management of threatened species and ecological communities during the assessment and approvals process.

## **Case study: Involving communities in mine life planning**

### **Gregory Crinum coal mine, Queensland, Australia**

Gregory Crinum is located 60km north east of the rural centre of Emerald and 375km north west of Gladstone in Queensland and consists of two mines. Operations at the Gregory open-pit mine commenced in 1979, while the nearby Crinum underground mine opened in 1995. Both mines are operated by BHP Billiton Mitsubishi Alliance (BMA). The open-pit and underground operations feed coal to a single preparation plant and rail load-out. The mines are situated in an area that has been extensively cleared for grazing and agriculture, but also contains areas of remnant vegetation, some of which have conservation value due to their scarcity. Current leading practice for new operations is to consult with the community at the earliest stages of the project. The community consultation methods used by BMA to develop its mine life plan are a good example of how existing mining operations can improve practices and involve stakeholders in helping to make key decisions on long-term land-use issues.

The process commenced with a public meeting held in September 2002. A community working group was formed from local stakeholders. This consisted of representatives of Landcare; environmental, regional planning and agricultural groups; local government; the Queensland Environmental Protection Agency; and Gregory Crinum mine management, environmental and community relations personnel. An independent facilitator was contracted to help manage the process.

Input from the group was used to help determine the best future use options for different land units (or domains) on the whole mining lease so that the mine could carry out the necessary earthworks, establish the right trees, shrubs and grasses—everything required to transform the plan into reality.



The group also helped develop criteria that will be used to judge whether Gregory Crinum's future rehabilitation efforts are successfully progressing towards that land use.

**Pasture and shelter trees on mine spoil**





### **Unmined Yellowwood scrub**

Specific success measures were developed based on the potential range of post-mining land uses. Categories of criteria included vegetation establishment (density, composition, species richness, and sustainability); management of dust, fire, weeds and feral animals; ecosystem function; connectivity, such as linking areas of environmental significance; post-mining land management; and sustainability of proposed post-mining land uses. Protection of remnant stands of Brigalow was recognised as important for the ongoing conservation of endangered ecosystems that are part of the habitat for the rare bridled nail-tail wallaby.



### **Bridled nail-tail wallaby**

A review process was developed to ensure the plan evolves over time to reflect changing community values and advances in scientific knowledge.

The community working group met 16 times over eight months. Members agreed that a number of land uses were possible on the various domains. These included native vegetation conservation, grazing, agro-forestry, recreation, cropping and industrial areas.

The ongoing review process will involve Gregory Crinum circulating information on any developments that may impact on the mine plan. Then, once a year, current members of the community working group and invited community members and groups will meet to review the mine life plan, measure current rehabilitation progress against success measures and, if necessary, make changes to the plan.

BMA is now using a similar approach to develop rehabilitation and mine closure strategies at the company's other coal mines.

Information for this case study was provided by BMA's Gregory Crinum Mine. Further information on the community consultation process used can be obtained by contacting BMA via [www.bmacoal.com](http://www.bmacoal.com).

## **2.2.2 Indigenous heritage management**

Approximately 60 per cent of mining operations neighbour Indigenous communities. For many operations Indigenous heritage management issues arise. Companies commonly seek external assistance to manage Indigenous cultural heritage issues, in recognition of the specialist skills required to successfully deal with these matters. Successful management systems and standards require early consultations and assessments with relevant Indigenous people to ascertain whether proposed activities are likely to impact cultural heritage values and, in conjunction with Indigenous people, how best to plan and undertake those activities to avoid or minimise such impacts.

A key issue is identifying Traditional Owners and other Indigenous people with rights and interests in the site. Knowledge about the site might be subject to cultural restrictions. Indigenous people are likely to describe the importance of a heritage place in general terms and may avoid discussing heritage places and values because of cultural sensitivities.

Monitoring and managing the impact of mining operations on local environments and the restoration of areas impacted by mining activities are significant issues for Indigenous communities and other stakeholders. In many cases, the only option acceptable to Indigenous people may be total protection of some sites. Indigenous community expectations of the rehabilitation process may include the restoration of a significant site that may have been removed or modified during mining. Indigenous management requirements may cover issues like salvage, removal and/or storage of cultural material impacted on by mining activity; and repatriation of material removed from the area for analysis.

In addition to its critical importance in the management of cultural heritage sites, Indigenous knowledge can provide valuable assistance in understanding the pre-mining environment of the site and the ecological interactions between individual species and ecosystems that can be critical for the successful establishment of native ecosystems in rehabilitation programs.

## **2.2.3 Non-Indigenous heritage management**

In addition to the need to include specific consideration of Indigenous heritage, mine sites also have the potential to include sites of significance for non-Indigenous history, particularly in areas where there has been a long history of settlement and mining.

While some of these sites may already be included on formal lists maintained by regulatory agencies, operations should never rely solely on regulatory agencies to identify all the relevant heritage values of a site.

A focus of community engagement should be on identifying any areas of community significance. This is particularly the case for views and other amenity values, where the formal recognition and protection of these values will vary widely between jurisdictions.

## **2.3 Sustainable development: the business case**

The business case for approaching mine rehabilitation within a sustainable development framework in a planned, structured and systemic manner that is progressively implemented over the whole project cycle includes:

### **Improved mine management**

- opportunities to optimise mine planning and operations during active mine life for efficient resource extraction and post-mining land use (for example reduction of double handling for waste materials and topsoil and reduced areas of land disturbance)
- identification of areas of high risk as priorities for ongoing research and remediation
- progressive rehabilitation provides opportunities for testing and improving the techniques adopted
- lower risk of regulatory non-compliance.

### **Improved stakeholder engagement in planning and decision-making**

- more informed development of strategies and programs to address impacts, ideally as part of a community development approach from early in the mine life
- improved community receptiveness to future mining proposals
- enhanced public image and reputation.

### **Reduction of risks and liabilities**

- assured financial and material provision for mine rehabilitation through more accurate estimation of mine rehabilitation costs
- reduction of exposure to contingent liabilities related to public safety and environmental hazards and risks.



## 3.0 PLANNING

### 3.1 Consultation during initial mine planning

During the initial planning of mine rehabilitation the focus should be on identifying existing groups and organisations within the community who are already engaged in similar activities. Groups such as Landcare, Greening Australia, farming organisations and custodians of traditional land practices have important local knowledge which can assist in minimising the impacts of mining and enhance the chances of successful rehabilitation.

Much of this early phase in rehabilitation planning is about establishing where there are gaps in knowledge and identifying research programs or site-specific trials to provide critical information. Consultation with key stakeholder groups at this stage can result in better targeted research and trial programs, and enhance the potential transfer of knowledge into community projects. In areas where extensive clearing has taken place, such as agricultural regions, this may result in rehabilitation programs being integrated into broader regional land management projects.

### 3.2 Legal requirements

Each Australian state and territory has its own legal requirements relating to handling and management of waste (spoil) materials at mine sites. Companies should contact the relevant statutory authority to discuss their requirements and any existing guidelines that may need to be considered.

### 3.3 Materials characterisation

Both waste materials and ore that are to be excavated can offer opportunities and risks for rehabilitation. Characterisation of topsoils and overburden should start as early as the exploration phase and continue through the pre-feasibility and feasibility phases as a basis for mine planning. Early characterisation of materials enables plans to be developed to avoid potential risks and to gain maximum benefit from material that may be particularly well-suited for construction for site infrastructure or for use in rehabilitation.

Characterisation of these materials should be undertaken to ensure that they do not have the potential to create an adverse impact or prevent successful revegetation being achieved during mining or at closure. The requirement for characterisation continues during the operation of the mine, particularly where the ore grade and mine plan change in response to altered market conditions.

Mine site structures such as run-of-mine (ROM) pads, haul roads or contractor laydown areas should only be constructed using 'benign' materials. Where possible, these structures should be placed in already cleared areas to minimise the amount of rehabilitation required.

For stabilisation and rehabilitation of landforms, characterisation of materials present may enable selective placement during landform construction to minimise risks of erosion or of revegetation failure. It may also enable remedial work, planning or investigations to be more timely and cost-effective.

The characterisation of materials normally involves mineralogical, physical, chemical and biological analyses. The value of the laboratory tests used in the characterisation of mine site materials is highly dependent upon the effective design of the sampling protocol. Dollhopf (2000), De Gruijter (2002) and Yates and Warrick (2002) provide useful guidelines for these activities.

Laboratory tests are extremely useful in identifying major limitations to stability or to plant growth. For some specific vegetation types, trials in the glasshouse (Asher et al., 2002) and on the mine site may be needed to assess more subtle aspects of the likely performance of different plant species in post-mining soils (Bell, 2002).

### **Mineralogical analysis**

Mineralogical analysis is a useful aid in characterising overburden, waste rock, spent heap-leach material and tailings as it can identify the presence and nature of potentially acid-producing sulfides, which can seriously affect plant growth directly through low pH values, or indirectly through creation of excessive soluble metal concentrations.

A comprehensive discussion of the tests suitable for assessing the mineralogical limitations of mine site materials to support plant growth is given in Dixon and Schulze (2002). Tests suitable for assessing the geochemical limitations of mine soils and mine wastes as growth media are described in Williams and Schuman (1987), Hossner (1988) and Sparks et al. (1996). MEND Manual Volume 2 (Tremblay et al, 2002) describes the approach developed in Canada for the sampling and geochemical analysis of mine site materials.

### **Physical analysis**

Physical tests enable an assessment of those properties important for plant growth, that is:

- adequate available water capacity to enable plants to survive periods of water stress,
- adequate internal drainage to preclude inhibition of root growth through lack of aeration, and
- non-limiting mechanical impedance to root penetration.

Additionally, physical tests exist to predict the susceptibility of soils and waste rock to erosion. This information is critical in constructing stable post-mining landforms.

Specific measurements of soil physical properties may include::

- particle size distribution
- plasticity of fine-grained tailings and soils
- density or porosity

- strength and compressibility
- water-holding capacity and hydraulic conductivity, both under saturated and unsaturated conditions.

Water storage capacity in a soil profile is generally defined as a plant available water capacity (PAWC), which is a function not only of the water storage capacity of a particular material, but also of the rooting depth that is provided. Drainage through the surface layers to depth is also a function of PAWC, being greater where PAWC is low.

The level of PAWC needed for good plant growth and minimisation of drainage to depth is a function of rainfall and rainfall pattern. However, there are, potentially, situations where low hydraulic conductivity of surface layers may limit water entry and may drastically reduce the water available to plants. Any water balance modelling that is done should consider impacts of soil properties on water entry and of plant growth on soil properties. Large increases in infiltration due to plant growth have been widely reported (Silburn et al., 1992; Scanlan et al., 1996; Carroll et al., 2000).

The physical characterisation of mine site materials is based largely on laboratory testing, supplemented by field testing to better represent field conditions and scale. Examples of field testing include large size sieving of coarse waste rock, estimating the particle size distribution of coarse waste rock by computer analysis of high resolution digital photographs, field density testing (including large-scale water replacement testing for coarse waste rock) and field permeability testing of waste rock, tailings and cover materials.

Tests suitable for assessing the physical limitations of mine site materials to support plant growth are described by Williams and Schuman (1987), Hossner (1988), Sobek et al. (2000) and Dane and Topp (2002).

### **Erodibility**

Broadly, erodibility describes the susceptibility of a given material to erosion. Due to the enormous differences in the erodibility of materials excavated during mining, the use of generic slope profile designs is unlikely to be consistently successful.

Erodibility can be predicted (with limited accuracy) on the basis of material properties or can be measured with greater accuracy using laboratory or field experimentation (Loch, 2000a). It is crucial that these measurements consider characteristic samples of the material of interest, and ensure that the material (when tested) is in a condition consistent with likely long-term field conditions. Testing of erodibility can involve laboratory or field studies using overland flows and simulated rain, or could use instrumented field plots under natural rain.

Soil properties that can directly affect erodibility include:

- infiltration capacity, which is affected by soil structure and structural stability, vegetation, and by soil fauna
- soil cohesion, which can affect rates of detachment of sediment
- sediment properties (size and density), which affect rates of sediment transport.

Rocky materials are typically resistant to erosion due to the relatively large size and high density of the rock particles that become exposed at the surface. Rock can be considered either as an intrinsic component of the material or as a mulch cover.

### **Chemical analysis**

One important consideration with respect to chemical properties of mine wastes is the potential for acid production from sulfide oxidation, and that topic is covered in detail in a related handbook.

Other important chemical tests for soils and wastes involve those properties which influence plant growth (pH, salinity, and nutrients), material stability, and tests for elements which may pose problems with water quality.

Even if the correct suite of analyses is undertaken on materials to assist in mine planning for operation and closure, the success of their characterisation will depend on the use of a rigorous sampling protocol to ensure that an accurate assessment of the material variability is captured.

### **Extremes of pH**

To achieve rehabilitation success, waste material or growth medium cover materials should be tested to ensure that the pH of the materials is within the range 5.5 to 8.5 commonly considered acceptable for plant growth, or is close to the pH levels of the local in situ surface soils. This recognises that there are certainly areas where native vegetation is adapted to pH values outside the 'normal' range.

The simplest chemical aspects to measure for potential growth media are pH and salinity. Despite the availability of quick and relatively cheap soil analyses, extremes of pH and salinity remain the most common causes of poor plant growth on rehabilitated areas.

### **Salinity**

Capillary rise of salt into covering (topsoil) layers and saline seepage can occur where saline materials are being excavated and placed in an above-ground landform. Elevated salinity can prevent seed germination, retard plant growth and reduce ecosystem diversity. Capillary rise of salt can be minimised by:

- using sandy topsoils, as their unsaturated hydraulic conductivity is lower than that of clay soils
- mixing rock with the topsoil to increase leaching
- using depths of topsoil greater than 500 millimetres.

### **Sodicity and potential to tunnel**

Sodic materials are generally defined as materials with greater than six per cent of soil cation exchange capacity dominated by sodium. Sodicity is of concern because sodic materials are subject to clay dispersion when wet. This can result in extremely low permeability and drainage, hard-setting when dry, and considerable potential for the development of tunnel erosion. Clay dispersion will be more significant in materials high in clay than in materials with less than 10 per cent clay. The degree of dispersion that occurs will also be affected by salinity, which tends to suppress dispersion.



Development of tunnelling is commonly noted at points on a landform where ponding of water has leached salt, triggering clay dispersion, and also provided a source of ponded water to drive the tunnelling process. Tunnel erosion can also be found in non-dispersive, fine, silty materials, and testing protocols need to consider the full range of potential tunnel erosion mechanisms.

Sodic materials are typically amended using gypsum (unless the soil already contains a high level of gypsum). Lime can be effective if the material being amended is also acidic.

Sodicity is generally assessed through analyses of exchangeable cations and Cation Exchange Capacity (CEC). For saline materials, care needs to be taken to distinguish between soluble and exchangeable cations.

### **Plant nutrients**

To gain a broad appreciation of soil nutrient status, analyses can be made for plant macronutrients (nitrogen, phosphorus, potassium and also calcium, magnesium and sulfur), together with a range of micronutrients. However, effective fertiliser application requires a detailed understanding of the specific rehabilitation conditions.

It is overly simplistic to suggest that native plants are 'adapted to low nutrient conditions and therefore do not need additional fertiliser'. This is not always the case; native vegetation may respond strongly to added nutrients if the soils that are stripped and replaced are in a degraded condition. Responses to specific nutrients may also vary and can sometimes offer the opportunity to favour development of a preferred species at the expense of its competitors. Equally, high nutrient levels, or high levels of a specific element, may aid the establishment of some weed species.

The way in which fertilisers are applied is also important. For example, spreading an immobile nutrient on the surface of a rehabilitated area may achieve little response as plant roots are seldom active in the surface.

As fertilising tends to be done once only at seeding the amount of fertiliser applied needs to achieve an initial response as well as long-term sustainability of the vegetation community that is developed.

### **Biological analysis**

Sustainable vegetation on post-mining landscapes, as part of a sustainable ecosystem, requires that above-ground and below-ground components operate within certain parameters. The first step to achieve sustainable revegetation is to conduct an assessment of the biological starting point of the post-mining materials, including the topsoil.

The key factors that should be considered are:

- Microbial biomass or activity of materials—this will give an indication of the level of residual biological activity in material and can be compared with the topsoil around the mine or another suitable analogue.
- Organic matter content provides the basis for biological activity prior to and during ecosystem rejuvenation. It also has a role in water retention and nutrient supply.



- Viable seed store in topsoil material—this is an essential requirement if native systems are to be restored or if weeds are to be controlled.
- Glasshouse trials can determine the suitability of test species to mining materials and more definitively assess nutrient deficiencies and potential toxicities than laboratory tests alone.
- Nitrogen fixers (both symbiotic and free living) are often the key to progressing the early stages in ecosystem development. These may be quite host specific and the presence of the correct organisms can be fundamental for the success of some plant species.
- Mycorrhizal fungi provide the primary mechanism of nutrient uptake in most native Australian plant species. This symbiosis is not as host specific as many nitrogen-fixers but is often important in underpinning stable below-ground nutrient uptake, enhancing drought tolerance and helping in pathogen suppression.
- Specialised assessments such as the presence of sulphur-metabolising bacteria may be required in specific cases.

These factors constitute the essential biological characteristics of materials, particularly those to be used as topsoil and in the rooting zone of plants.

A range of other biological factors, such as 'ecosystem engineers' (mainly invertebrates such as springtails, collembola, ants, termites and earthworms that break down organic matter and aerate soil) and pollinators, may have essential roles to play in the reconstruction of terrestrial ecosystems on mining materials, and should be considered.

### **3.3.1 Materials segregation and selective placement**

Comprehensive characterisation of soils, overburden and wastes provides the basis for rigorous segregation and selective placement of materials to achieve a sustainable vegetative cover and to prevent contamination of both surface and groundwater resources.

Except in a limited number of circumstances, establishment of sustainable ecosystems after mining generally requires the conservation and replacement of soil resources over the mined area. Issues that need to be systematically addressed include:

- the selection of the soil horizons to be conserved:
- the process of soil removal and placement:
- the effect of stockpiling on soil properties; and
- the optimum depth of replaced soil.

Segregation and selective placement of overburden layers is practised for two reasons, that is;

- 1) to bury material which is adverse to plant growth or which may contaminate surface or groundwater supplies: and

- 2) to salvage materials that will assist in the rehabilitation program. Particular overburden strata may be undesirable because of their salinity, sodicity or potential to produce acidity through sulfide oxidation.

Mineralogical, physical and chemical analyses of drill cores and chip samples at the earliest stage of mine development allow the waste rock around an ore body to be block modelled in the same manner as for the ore. Classification of the overburden, in terms of such factors as potential acid generation capacity, susceptibility to erosion, and limitations to the support of plant growth, provides the basis for the effective segregation of materials during waste rock dump construction.

Where the pre-mining overburden contains sulfidic material that may produce acid drainage, the surface weathered (oxidised) zone is a valuable resource and care needs to be taken to ensure that this material does not end up being buried by sulfidic rock at the end of the mining operation.

It is important that experienced personnel are involved in classifying the various waste rock types and in overseeing its removal and placement during waste rock dump construction. Failure to maintain quality control in this phase of the mine operation can jeopardise environmental protection, both during operations and following closure.

Establishment of sustainable vegetation on tailings may require covering the materials with soil or benign waste rock. In some situations, segregation of tailings in terms of particle size and/or mineralogy in the metallurgical plant may be able to be used at the later stages of deposition to create a non-hostile material capable of supporting plant growth.

### **3.3.2 Material budget and schedule**

It is important that mine planning be undertaken to calculate the volumes of suitable materials required for the various rehabilitation purposes such as materials to form the 'B' horizon of the cover soil profile, the surface growth medium to be placed over the 'B' horizon, material to encapsulate sulphidic waste.

The material budget and the location of the materials is then integrated with the mine plan to minimise double-handling and stockpiling (especially long term) of these suitable materials. Material budgeting and scheduling ensures that the correct materials are available at the time required for their placement in the rehabilitation process.

## **3.4 Site assessment**

Designs used for rehabilitation works have in the past tended to be relatively fixed, applying specific landform designs and construction practices virtually irrespective of location or material properties. There is now increasing interest in developing rehabilitation plans tailored to correctly handle and position the materials present, use the prevailing environment, and take the required final land use into consideration.

### 3.4.1 Protection measures

#### Rare and endangered species

Rare and endangered native plant and animal species are protected under Australian and state and territory legislation. The controlling Commonwealth of Australia legislation is the *Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)*.

Assessment of the impact of any mining proposal is undertaken by statutory authorities before approval to proceed is given. Any potential adverse impact on rare and endangered species will need to be managed and mitigated to the satisfaction of the regulatory authority.

#### Heritage sites

Australia has numerous ways of identifying and protecting important heritage places. Decisions about managing heritage places are carried out under laws at all levels of government. States and Territories have primary responsibility for protecting cultural heritage. All States and Territories have legislation which provides blanket protection to Indigenous archaeological sites. At present State and Territory laws have quite different definitions of Aboriginal cultural heritage. Some laws, including the Commonwealth, protect areas and sites that are significant in accordance with Aboriginal tradition. The laws of other jurisdictions have definitions which focus on 'relics' or archeological sites and do not give weight to Aboriginal cultural values.

The EPBC Act is the Australian Government's key national heritage law. The EPBC Act enhances the management and protection of Australia's heritage places. Any action that is likely to have a significant impact on a World Heritage property or a national heritage place must be referred to the Commonwealth Environment Minister for further consideration.

The *Aboriginal and Torres Strait Islander Heritage Protection Act 1984 (ATSIHP Act)* is Commonwealth legislation that provides for the preservation and protection from injury or desecration of areas and objects in Australia and in Australian waters that are of particular significance to Aboriginals in accordance with Aboriginal tradition. This Commonwealth Act is intended to cover situations where the State or Territory laws do not give effective protection to an area or object, which is under threat. Protection will not be given under the ATSIHP Act where State or Territory laws are considered effective.

Where a development might impact upon an Indigenous value, place or site, developers are required to seek approval under State/ Territory law, and in some circumstances Commonwealth law. Early and culturally appropriate consultation with Indigenous people is a key element in the assessment and management of impacts on Indigenous heritage values.

### 3.4.2 Climate

Climate has enormous impacts on landform stability and site rehabilitation. Evaluation of site climate is essential to ensure that:

- goals for rehabilitation and final land use are realistic
- plant species used are appropriate
- soil profiles developed are suitable for plant growth
- landforms are designed to be stable under the prevailing conditions
- cover systems are designed appropriately.

Climate data tend to average out extreme weather conditions. Therefore, planning should consider not only long-term average conditions, but also shorter-term extremes of drought, wind and rainfall.

Seasonal rainfall can have considerable impact on landform and vegetation performance. Where there are distinct wet and dry seasons, the timing of rehabilitation can be critical to its success.

### 3.4.3 Growth media

Growth media refers to materials placed on the surface of a rehabilitated area or landform with the expectation that they will support plant growth. Such materials are commonly the topsoils harvested prior to mining, though not necessarily so. Timing, soil condition, and handling techniques all influence the ability to retain soil structure and to reduce compaction. It is essential that the limitations to plant growth in a given area be fully understood prior to planning rehabilitation works.

In some cases, topsoil contains a heavy seed burden of weeds or undesirable species. To avoid the spread of these species, it may be necessary to treat the vegetation prior to topsoil collection or use materials excavated from greater depths. However, in many cases, the biological component of topsoils can be very important. It contains a seed load which could include species difficult to obtain or germinate as well as a range of micro-organisms that can improve plant growth and stabilise the soils. In these cases, proper management of the soil to minimise damage to its micro-organisms can be crucial.

### 3.4.4 Salt budget

For many mine sites, some or all of the water available for use may be saline, particularly if it is recycled. A consequence of water use is the movement of salts around the site and, potentially, accumulation of salts at various locations. For example, if saline water is used for dust control on roads, then those roads will accumulate salt which may affect their eventual rehabilitation. Other potential sites for salt accumulation are evaporation ponds and sediment traps.

The site water budget should be closely linked to the salt budget. This ensures that potential areas of salt accumulation are identified and their management is planned to minimise long-term problems.

## **3.5 Planning the rehabilitation program**

If the initial site assessment (discussed in Section 3.3) indicates significant risks or issues for rehabilitation, then research needs to be undertaken to develop and validate methods (controls) for managing those risks and for monitoring the success of the techniques adopted. This should not delay the development of a comprehensive rehabilitation plan for the mine site. Results from research and on-site rehabilitation trials are used to modify the plan throughout the life of the mine in a process of continual improvement.

### **3.5.1 Landform design**

It is critical to design landforms to minimise the costs of construction and to minimise the costs of long-term maintenance. Traditionally, waste has been dumped to form landforms to a design height, with outer slopes being dozed down at a later date. Dozing down of angle-of-repose outer batter slopes can lead to considerable multiple handling of material, and crushing and alteration of otherwise competent rock. Where possible, dumping should be planned to meet requirements for selective placement of materials and to minimise the costs of final shaping.

It is important to agree on the objectives for a particular landform in terms of final land use, stability, community expectations and long-term management. Detailed landform design should not be attempted until these objectives are clearly articulated.

#### **Placement of landform**

Constructed landforms need to be sited so they do not interfere with potential future excavations (including pit expansions) or access to new ore bodies, and this frequently requires sterilisation drilling to confirm the proposed location.

Consideration should be given to existing overland flow paths on the site to ensure that the landform does not divert or obstruct any major streams. Placement of landforms too close to lease boundaries can create problems for sediment management and dust control, and can restrict future management options. Impacts on fauna movement and access to watering points should also be avoided. In some cases, it is possible to blend constructed landforms into the landscape, thereby minimising visual effects and addressing potential community concerns.

#### **Height/footprint**

The area of land disturbed by landform construction (the footprint) should be minimised. However, efforts to minimise the footprint can lead to the construction of steep, high landforms with little potential for stability. In addition, steep, high landforms may not blend in with surrounding natural landforms. Therefore, it is important to identify the height of landform that can be constructed successfully – that is, encapsulating reactive wastes without significant risk of subsequent erosion – so that long-term maintenance can be avoided or minimised.

The stable height that is possible will depend on:

- erosion potential (erosivity) of the climate
- erodibility of the surface materials, including waste rock, spoil and growth media
- height and gradient of slope created
- likely vegetation cover
- the outer batter profile adopted (linear, concave, convex) and how it is constructed.

If the stable height identified is lower than considered economically or practically desirable, then options for further stabilisation of the landform, such as the placement of rip-rap on the outer slopes, can be investigated.

### **Drainage**

If the landform contains materials of concern (potential for acid drainage or transport of some pollutant), then it may well be advisable to discharge run off from the top of the landform rather than retain it and potentially increase drainage to depth. Equally, establishment of deep rooted tree species to minimise deep infiltration could be considered, provided the surface growth medium layer has sufficient depth. Where encapsulation is important, waste dump design needs to consider both control of deep drainage (which could increase potential for undesirable seepages) and minimisation of erosion (which could ultimately expose the encapsulated material).

Discharge of run-off from the top of waste dumps carries significant risk. In many situations, run-off from the top of the landform is concentrated so that some form of stable flow line is then required to carry the water to ground level, where a controlled discharge point will be required. Rock drains or chutes are commonly used, but the rate of failure of these types of structures is extremely high. Where vegetation cover levels – particularly grass – are high, it is possible to have run-off from the top of a landform discharge evenly and gently onto outer batter slopes and move to ground level without damage. In these situations, high levels of surface contact cover are essential. However, the discharge of run-off also reduces the water available to sustain such vegetation, particularly in a dry, seasonal climate.

If run-off is retained on the top of the waste dump or tailings storage facility, it is essential that the potential for prolonged ponding and damage to plants be considered. There is also potential for water ponded on top of a landform to cause subsidence within the loosely-dumped materials present, creating sink-holes. For these reasons, the depth and duration of ponding at any point on the landform surface should be minimised. This can be achieved by keeping the top of the landform level, maximising surface roughness, and installing bunds to create relatively small cells of one to three hectares. Establishment of vegetation to increase water use is also appropriate.

## **Mode of construction**

Construction of landforms varies considerably, often largely dictated by excavation methods. For example, dragline spoil piles offer little option for selective placement, whereas truck/shovel operations do enable selective placement to encapsulate problem materials, or to ensure that more stable materials are placed on the outside of the landform.

A range of software is available to enable companies to optimise the costs of waste dump construction by ensuring optimal haul and dumping schedules. However, most of this software has inbuilt assumptions that impact on the results, and these must be clearly understood to achieve the planned outcome.

## **Profiles**

Constructed outer batter slopes have traditionally been linear with berms installed at some set vertical interval to intercept run-off. The berms may be intended to pond water or may be designed to convey run-off to rock drains.

In general, erosion of constructed landforms on mine sites is dominated by gullying—a direct consequence of concentration of run-off by the berms and discharge of concentrated flows onto batter slopes once the berms fail. The reasons for berm failure include inaccurate construction, tunnel erosion and overtopping due to deposition of sediment. Where erosion rates remain significant (commonly in arid areas where surface vegetation cover is too low to provide erosion control) outer batter profiles that include berms will require regular maintenance (de-silting) as long as the erosion continues, or else they will fill with sediment and overtop, causing gullying.

For this reason, some sites have adopted a practice of using berms or some form of across-slope bank during initial rehabilitation, then removing the berms once vegetation has established and stabilised the slope.

Other sites have incorporated rock into the surface of outer batter slopes to reduce erosion potential and enable them to construct relatively long, high, slopes without berms. Another option is to create concave slope profiles to reduce erosion potential; usually by a factor of two or three.

Surface roughness is an important consideration in rehabilitation of mine site landforms. Roughness tends to trap water and seed, and there is general acceptance that a rough surface will provide better vegetation establishment than a smooth one. However, while the creation of large surface roughness via rip lines or moonscaping may give benefits in the short term, in the longer term it may lead to increased erosion and instability of the landform. This is covered in greater detail by Landloch (2003). The value of surface roughness is closely linked to its persistence through time, which is largely controlled by the particle size distribution of the material in which the roughness is created.

## Case study: Murrin Murrin nickel operation, Western Australia

The Murrin Murrin Nickel Cobalt Project (Murrin Murrin) is located in the north eastern goldfields region of Western Australia. Murrin Murrin, owned by Minara Resources Ltd (60%) and Glencore International AG (40%) mines laterite ores and utilises high pressure acid leach technology to recover nickel and cobalt from those ores. Initial waste dump construction followed standard guidelines, with 10 metre-high lifts creating batter slopes of 15 to 20 degree gradient separated by five metre-wide, water-retaining berms.

It was identified that waste dump construction could be improved to eliminate the development of gullies on batter slopes due to:

- discharges from the tops of the waste dumps
- overtopping and piping of berms
- occasionally from flow concentrations caused by the cross-slope ripping that was carried out as part of rehabilitation operations.

The site also lacked materials such as competent rock or coarse wastes that could be used to stabilise batter slopes.

To develop a new approach to waste dump construction, Murrin Murrin had the erodibility of a range of wastes and topsoils assessed using both laboratory and field measurements. Using that data and long-term rainfall and climate data for the site, computer simulations of run-off and erosion were used to compare a range of options for outer batter slopes. Concave slope profiles were developed that had relatively low erosion risk, though addition of tree debris and laterite gravel was recommended for segments of the slope that the simulations showed to have highest erosion potential.

Where complete waste dump rehabilitation was possible, rehabilitation designs included:

- bunding to retain run-off on the top of the dumps
- cross-bunding and ripping on the top of the dump to minimise the potential for significant concentration of run-off at any point
- concave outer batter slopes with no berms to concentrate flow or trigger gullies
- strategic placement of tree debris and laterite to provide additional erosion protection at points of highest erosion potential
- material characterisation to develop fertiliser and amendment recommendations.

Although the waste materials are not strongly susceptible to tunnel erosion, there is always potential for tunnels or sink-holes to develop in the tops of waste dumps. By minimising concentration of run-off on the top of the dumps and by keeping any potential ponding well away from the crests of the batters, potential for a sink-hole to pipe through to the outer batter slopes is kept very low.



Concave slope profiles more closely resemble natural landforms and tend to reduce erosion by a factor of two to three relative to linear slopes of the same average gradient. They should be designed on the basis of site climate and the properties of the materials present on site.

At this stage (one to two years after construction), waste dump batters constructed to specification have shown little run-off or erosion even after experiencing one 1:10 year daily rainfall. This has confirmed that the relatively conservative design process has overestimated run-off and erosion potential (as intended). With time, it is expected that the batter slopes will show some erosion, but that the long-term rates of erosion will be low.

This approach has eliminated mechanisms by which waste dumps failed previously, and substituted a transparent planning process based on accepted scientific procedures.



**Concave slope at Murrin Murrin Nickel Operation soon after construction**

### **3.5.2 Rehabilitation processes**

#### **Progressive rehabilitation**

Progressive rehabilitation during the life of the mine will help to reduce the overall liability for rehabilitation works particularly after decommissioning of the site when there is no direct income to offset costs. It also provides an opportunity for testing rehabilitation practices, and for the gradual development and improvement of rehabilitation methods. Visual amenity will also be improved.

For individual landforms, progressive rehabilitation may be useful where establishment of vegetation can provide significant increases in the stability of outer batter slopes. By rehabilitating relatively short slope lengths at the same time, it is possible to gradually construct a longer, stable slope without the erosion damage that would occur if the complete slope was constructed and rehabilitated at the same time.

Successful implementation of rehabilitation provides credibility for the mine operator, and encourages statutory authorities to give credit when assessing the value of rehabilitation bonds.

#### **Vegetation type/community/seed/propagules**

Around Australia it is common practice to use local provenance species of native plants for mine rehabilitation. Where feasible, it is often planned that vegetation established on rehabilitated land be similar to the vegetation type and community that was present before mining started.

It is also essential that as much of the local seeds and propagules contained within the top few centimetres of soil be retained for later revegetation programs.

#### **Voids and diversions**

All openings developed for underground mining, or voids that occur on the surface through subsidence collapsing of stopes, are required to be made safe—either by fencing off, sealing or filling in.

All open pits are required to be made safe. The construction of a large bund around the pit (and installed outside the area of potential wall failure) or fencing should be considered. Statutory authorities are likely to impose minimum standards for this work.

At some open-pit mine sites, mine planning may permit adjacent pits to be in-filled using material sourced from pits that are mined later in the mining program.

In strip mining (used in the surface coal mining industry), the previous void is backfilled using material from the new excavation.

It is normal procedure for surface water diversions to be re-instated to their former location at the end of mining, whenever and wherever this is possible.

## Case study: Mt Owen coal mine, Hunter Valley, NSW

Mt Owen Mine is an open-pit coal mine located in the Hunter Valley of New South Wales. Mt Owen is owned by Xstrata Mt Owen (XMO), a 100 per cent owned subsidiary of Xstrata Coal. The mine is operated by Thiess Pty Limited under a partnering agreement with XMO and is approved to produce up to 10 million tonnes of run-of-mine coal per annum for the export market until December 2025.

Mt Owen is mining through an area of the Ravensworth State Forest (RSF). The RSF is considered to be a highly significant remnant on a local and regional scale and is one of the largest remaining areas of remnant woodland on the central Hunter Valley floor. Since 1995, 145 bird species, 24 non-flying mammals, 18 bat species, 20 reptile and 15 amphibian species have been recorded in the RSF or adjacent land. Nineteen threatened fauna species listed on the *NSW Threatened Species Conservation Act 1995* have been recorded at Mt Owen, including the green and golden bell frog, squirrel glider, spotted tailed quoll, and a number of bat and woodland bird species. This presents Mt Owen with a unique challenge in terms of offsetting the impacts of mining activities on native flora and fauna communities and rehabilitating mined areas back to a native forest and woodland community.

In recognition of the significance of flora and fauna communities within the project area, Mt Owen has implemented innovative practices to offset the impacts of mining on native flora and fauna and to provide for a substantial improvement in the ecological values of the project area in the medium to long term.

Mt Owen's flora and fauna management program incorporates mine site rehabilitation and adjacent native vegetation communities within mine buffer areas. The program is guided by a comprehensive flora and fauna management plan, which was developed by an advisory group consisting of representatives from NSW government departments, the Hunter Environment Lobby and Mt Owen. The principal objective of the plan is to guide flora and fauna management, and rehabilitation and revegetation practices at Mt Owen. Implementation of the plan is overseen by the advisory group.

The key components of the Mt Owen flora and fauna management program include:

- establishment and management of biodiversity conservation areas to offset mining impacts
- progressive rehabilitation of disturbed areas to native woodland
- implementation of specialised flora and fauna management techniques
- comprehensive flora and fauna monitoring program
- on-going program of native forest restoration research in conjunction with the University of Newcastle's Centre for Sustainable Ecosystem Restoration.

Specialised management measures are used at Mt Owen to minimise impacts on native fauna during the clearing process and to provide a resource to enhance the regeneration of native indigenous vegetation within designated rehabilitation and conservation areas. These measures include:

- Clearing is staged to occur as close as practicable to the mining of the cleared area.
- Clearing is timed to avoid the breeding cycles of relevant threatened fauna species, where practicable.
- Fauna surveys are conducted prior to issuing a clearing permit.
- Habitat trees are identified and marked prior to clearing. Identified habitat trees are only cleared following the removal of surrounding vegetation and inspection by an experienced fauna consultant to determine whether native fauna species are present.
- To augment the clearing of nesting and diurnal roosting habitat for a range of fauna, nest/roost boxes designed for specific target species are placed at heights, aspects and on structures appropriate to the target species in rehabilitation and conservation areas.
- Large ground debris and standing dead timber is collected for redistribution in rehabilitation and surrounding conservation areas, where practicable. Any remaining material is mulched for use in rehabilitation.
- To maximise the use of seed and propagation material from existing indigenous native grasses, herbs, shrubs and trees, recoverable viable seed is collected prior to clearing for use in revegetation programs at Mt Owen.
- Topsoil is removed following vegetation and mixed with mulched vegetation for subsequent use in rehabilitation and planting projects.
- Where possible, the timing of forest topsoil removal is coordinated with open-pit operations to ensure minimal handling and storage. Forest topsoil contains an important reserve of indigenous plant seeds and soil microflora, which will assist with the preservation of local genetic material and the re-establishment of a similar range and mix of species to that of the original vegetation in rehabilitation areas.
- Rehabilitation of disturbed areas is undertaken using endemic species.
- Domestic stock is excluded from rehabilitation and conservation areas.

Unique rehabilitation techniques are being developed by Mt Owen through its ongoing monitoring and research program. Areas of remnant vegetation surrounding mining areas are used as control sites for comparison with rehabilitation areas. Information obtained from this monitoring is used to guide and continuously improve rehabilitation efforts at the mine.

Monitoring and research is also being undertaken in adjacent buffer lands to assist with restoration of the Ravensworth State Forest remnants and other biodiversity conservation areas. These conservation areas are contiguous with rehabilitation areas and will provide an important source of recruitment for native plants and animals.

The most significant strategy proposed to mitigate the loss of regionally significant vegetation communities as a result of mining at Mt Owen is the formal conservation of woodland communities through a Biodiversity Offset Strategy (BOS). The BOS involves the rehabilitation and remediation of pasture and isolated woodland remnants adjacent to currently vegetated areas, which will enhance the long-term viability of the RSF and surrounds. Combined with existing conservation areas at Mt Owen and the life-of-mine rehabilitation program, the BOS will deliver an area of native woodland about five times larger than the original woodland community that existed prior to mining.

Mt Owen's flora and fauna management program provides protection for establishing woodland communities in rehabilitation areas and in adjoining mine-owned buffer land. Conservation areas adjoining mine rehabilitation areas are also being expanded and enhanced through proactive intervention and the restoration of scattered woodland remnants and pasture areas to provide similar vegetation communities and opportunities for movement of flora and fauna into rehabilitation areas. The short-term aim is to conserve existing flora and fauna in conservation areas through effective management, while establishing new areas that will provide a self-sustaining system in the long term. The long-term aim is to provide a self-sustaining flora and fauna conservation reserve with sufficient size to provide the necessary diversity, while providing corridor linkages to the larger vision for integrated landscapes in the Hunter Valley. This reserve will establish a core area that can be connected by corridors to other remnant vegetation on the floor of the valley and adjacent footslopes.



**Flora and fauna monitoring is undertaken in rehabilitation areas and surrounding mine buffer land.**

Source: Xstrata Coal



## 4.0 OPERATIONS

### 4.1 Consultation during mine operations

The key focus of engagement during the operational phase of mining should be on engaging the community and regulators in the development and review of rehabilitation plans, and on building the capacity of the local community to assist, where appropriate, in rehabilitation works. In particular, activities such as seed collection and storage, nursery production of seedlings and the control of invasive plant and animal species can provide both a valuable point for community engagement and local business development.

Many Australian plant species are difficult to propagate and the specific treatments needed to ensure adequate germination vary widely. Small-scale trials by local groups and individuals can assist in the successful propagation of recalcitrant species.

### 4.2 Materials characterisation

Mine site materials include ore, benign and reactive waste rock, tailings, cover materials and soils. As outlined in section 3.3.1 of this handbook, the characterisation of mine site materials should start early in the exploration phase of a mining project and continue through the operational phases as a basis for long-term mine planning.

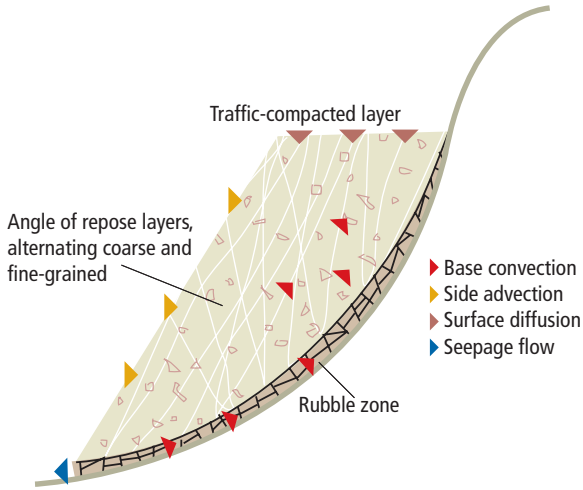
Limiting environmental impact from land disturbed by mining and mineral processing and achieving sustainable mine site revegetation depends on the propensity of the reconstructed surface materials to support plant growth, in terms of their water-holding capacity, their mineralogy and geochemistry, and their microbiological attributes.

### 4.3 Materials handling

Typically, the strata overlying the groundwater table have been exposed to atmospheric oxygen and are oxidised, while the strata underlying the groundwater table have been denied access to oxygen and are prone to oxidation on exposure to the atmosphere. The mineralised halo that surrounds an ore body will typically include sulphides below the groundwater table, which will oxidise to sulphates on exposure, resulting in a drop in pH and the dissolution of metals at lowered pH.

Waste rock piles are typically constructed by trucks, using either paddock-dumping or end-dumping off a tip-head. End-dumping results in the formation of an 'oxidation reactor' (Figure 1) with a base rubble zone formed by the ravelling of large boulders to the toe of the advancing pile face and discontinuous, angle-of-repose (about 37° to the horizontal) alternating layers of coarse-grained and fine-grained waste rock above the base rubble zone. The base rubble zone provides a ready entry point for oxygen, which flows up the coarse-grained angle-of-repose layers, diffusing from there into the fine-grained angle-of-repose layers that present a much higher reactive surface area per unit volume.

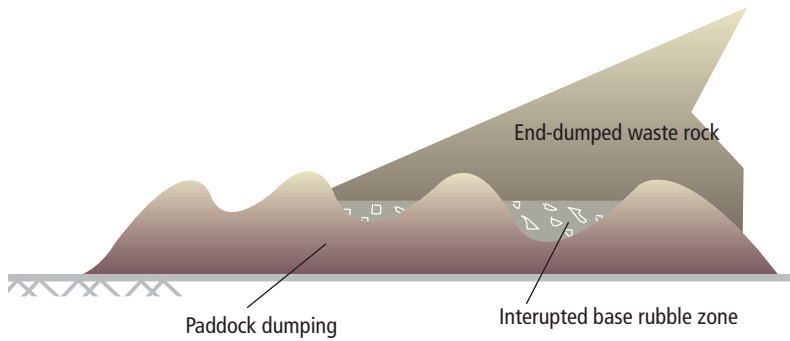
**Figure 1: End-dumped waste rock 'oxidation reactor'**



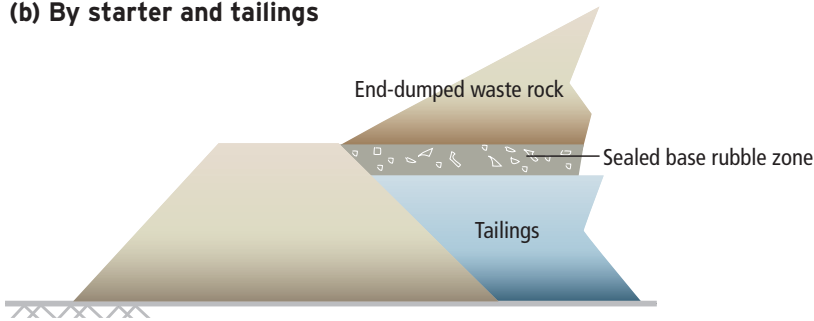
To limit the ingress of oxygen into the dump, the base rubble zone may be interrupted by paddock-dumping at the base prior to end-dumping, end-dumping into stored tailings, or by an engineered solution (Figures 2(a), (b) and (c), respectively).

**Figure 2: Means of interrupting base rubble zone of end-dumped waste rock pile**

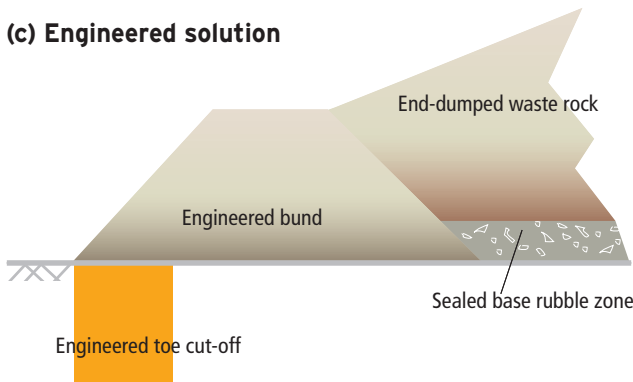
**(a) By paddock-dumping**



**(b) By starter and tailings**



**(c) Engineered solution**



The benign, oxidised materials first encountered in open-pit mining (at shallow depth above the water table) should be used to encapsulate the typically sulphidic materials later excavated (at depth below the water table). The oxidised waste rock should be used to construct base and side encapsulations in advance to contain the reactive waste rock (Figure 3).

**Figure 3: Encapsulation by benign materials of reactive wastes**



An accurate characterisation and budgeting of the waste rock streams is required to ensure that there is sufficient benign waste rock to encapsulate the subsequent reactive waste rock. The budgeting and sequencing of benign, oxidised waste rock relative to reactive waste rock may be enhanced by developing the open pit as a series of cut-backs, rather than as a single operation covering the final pit footprint.

In a similar way, the oxidised ore excavated from above the water table will produce oxidised and typically benign tailings, while the sulphidic ore excavated from below the water table will produce potentially acid-generating tailings.



It is difficult to avoid depositing reactive tailings over earlier deposited benign tailings, unless the open pit is developed as a series of cut-backs. Particular consideration must be given to ensuring that sufficient benign material is available for covering reactive tailings.

Waste rock piles and tailings storages should be designed and constructed with a view to the final landform design, which should, as far as possible, mimic natural landforms, surface textures and vegetation patterns.

For more information on tailings management, see the Tailings Management handbook in this series.

## **4.4 Mine waste water balances**

### **4.4.1 Waste rock**

An operating waste rock pile closes off evaporation from the natural land surface (evaporation being several times greater than rainfall in arid and semi-arid regions), while allowing rainfall infiltration (Williams, 2006). Initially, rainfall infiltration may be dominated by flow along preferred pathways, but as the wetting up of the pile increases, continuum flow will start to dominate. A proportion of the rainfall infiltration will go into storage within the voids in the pile, with any excess infiltrating further into the pile, ultimately emerging as seepage at the toe and into the foundation.

Due to its very low hydraulic conductivity, the initially dry waste rock will store infiltration from light rainfall events. A high waste rock pile of relatively dry material may be capable of storing the infiltration from several years of rainfall. The wetting front will progress through the pile as the ability of the waste rock pores to store water is exceeded, this occurring well below the fully saturated state (perhaps 25 per cent saturated for fresh, coarse-grained waste rock up to 60 per cent saturated for weathered, well-graded waste rock). As the degree of saturation of the waste rock pores rises, so too will the hydraulic conductivity and the ability to pass water. The longer the waste rock pile is left uncovered, the more it will 'wet up'. The lower the height of the pile and the higher the rainfall, the more rapidly this will occur. Ultimately, the pile will wet up to the point where there are continuous water pathways, allowing 'breakthrough' seepage from the toe of the pile and into the foundation.

Initially, percolation into the foundation is limited by the very low hydraulic conductivity of the unsaturated zone within the foundation. A wetting up front will advance downwards, aided by any preferred seepage paths, raising the hydraulic conductivity of the unsaturated zone and causing groundwater mounding, with any contaminants in the seepage able to reach the groundwater.

The amount of rainfall infiltration into the pile can be restricted by sloping the traffic-compacted top surface to avoid ponding and increase run-off. The loose-dumped outer slopes of the waste rock pile should be constructed of benign waste rock of sufficient thickness to produce clean run-off and seepage.

The water stored within the pile during its operation and prior to it being covered will continue to seep for many years (Williams et al., 2006) – perhaps for as long as the pile was uncovered – even though the placement of a cover on the top of the pile will

significantly reduce further infiltration into the pile. 'Store/release' cover systems have been shown to limit infiltration to one per cent of average annual rainfall, and perhaps up to five per cent of unseasonally high annual rainfall totals (Williams et al., 2006). Seepage from the toe and percolation into the foundation (accompanied by the transport of contaminants) will diminish over time as the waste rock drains and loses hydraulic conductivity. Percolation should eventually cease, with the residual moisture within the pile held in place by pore water suction. Any groundwater mounding beneath the pile will subside over time, eventually returning to its original elevation.

For the side slopes of the pile, no sustainable, low-percolation cover system has been developed, although a reactive waste-rock pile in the wet tropics has been covered with a geomembrane and, in the Pennsylvanian Coalfields, reactive coal washery wastes have been covered with low hydraulic conductivity covers comprising fly ash or cement. The side slopes of most piles will remain prone to infiltration during heavy or continuous rainfall and it is, therefore, essential that they be constructed using benign waste rock of sufficient width to ensure clean run-off and seepage.

#### **4.4.2 Tailings**

An operational surface tailings storage allows tailings water and rainfall to infiltrate, wetting up the foundation and containment walls (Williams, 2006). The conventional disposal of tailings as a slurry involves continual flooding of the tailings surface. While some water will remain entrained within the tailings, the remainder will evaporate from the decant pond and wet tailings or seep into the foundation and through the containment walls.

The amount of seepage can be restricted by placing tailings that are as dry as possible and efficiently removing supernatant water.

Tailings deposition could be cycled between cells to maintain unsaturated conditions within the base pad underlying the tailings and ensure no saturated breakthrough into the foundation.

Initially, percolation into the foundation is limited by the very low hydraulic conductivity of the unsaturated zone within the foundation. A wetting front advances downwards—aided by any preferred seepage paths—and raises the hydraulic conductivity of the unsaturated zone causing groundwater mounding. Contaminants in the seepage are able to reach the groundwater. The outer containment walls are typically constructed of waste rock, which should be benign and of sufficient thickness to produce clean seepage and run-off.

The water stored within the tailings during the operation of the storage facility will continue to seep for many years after closure. Percolation (and the transport of any contaminants) into the foundation will diminish over time as the tailings drain and lose hydraulic conductivity. Provided that rainfall run-off is not concentrated locally on the tailings surface but is spread to enhance evaporation, percolation should eventually cease in an arid or semi-arid climate, with the residual moisture entrained within the tailings held in place by pore water suction. Any groundwater mounding beneath the tailings storage facility will subside over time in dry climates, eventually returning to its original elevation.

Given the relatively low hydraulic conductivity of tailings, particularly as it desaturates, it may not be necessary to use a cover to limit infiltration, provided the tailings are not allowed to fully resaturate by long-term concentrated ponded water. A net evaporative moisture flux should persist within the tailings, despite periodic rewetting for short periods following rainfall events. However, a cover may be desirable and necessary for revegetation purposes. Overtopping of the outer slope of the tailings containment should be avoided to limit erosion.

For more information on tailings management, see the Tailings Management handbook in this series.

## **4.5 Landform reconstruction**

Mined landform reconstruction is aimed at cost-effectively achieving a sustainable post-mining land use while managing the risk of environmental impact and limiting the need for ongoing maintenance. Mined landforms should mimic natural landforms as much as possible.

Natural hillslopes differ from constructed mine waste rock slopes in a number of crucial ways. While mine waste rock slopes are generally constructed and reshaped to a linear profile, natural hillslopes are generally concave-shaped, which tend to capture erosion sediment on the slope, and are of diverse angle, length and surface texture. Natural hillslopes are protected from erosion by rock armouring, cemented cap rock and vegetation. Mine waste rehabilitation earthworks should aim to reconstruct similar distributions of slope angles, slope lengths, vegetation patterns to those that were in place prior to mining.

Fluvial geomorphic mine waste rehabilitation design principles, such as those used at La Plata and San Juan coal mines in the Badlands of New Mexico (BHP Billiton, 2001), should be employed in preference to linear engineering design principles.

## **4.6 Covers**

Covers over the flat-top surfaces of mine waste storages in a dry climate such as Australia's are designed primarily to limit rainfall percolation into the underlying mine wastes and, thereby, limit potentially contaminated seepage from the mine wastes. Limiting oxygen ingress into the mine wastes is difficult given the likely unsaturated nature of the mine wastes, although a moist cover will provide some barrier to oxygen ingress.

### **4.6.1 Natural analogues**

In Australia's arid and semi-arid regions, where many of our mines are located, the groundwater is deep, with a very low permeability, unsaturated zone above. Streams are predominantly ephemeral, underlain by a perched underground stream in a sand or gravel bed, which itself is underlain by an unsaturated zone above the groundwater table. The base of the underground stream is effectively 'sealed' by fine sediments, delivering limited water to the unsaturated zone beneath and maintaining its unsaturated state and very low permeability. If this were not the case, all surface water would rapidly percolate to the groundwater table, which has ample porosity to store it.

Covers over mine wastes should mimic the function of ephemeral streams, with a storage layer in the upper part underlain by a sealing layer to limit percolation into the underlying mine wastes. This will ensure they remain unsaturated and of low hydraulic conductivity.

#### 4.6.2 Possible components of a cover system

Possible components of a cover system over mine wastes involve, in sequence from the surface, the following:

**Topsoil:** normally a key component, which requires a high water storage capacity and sufficient depth for plant roots (greater than 0.5 metres). This is preferably friable, aggregated with biological activity, and has a reasonable nutrient supplying capacity.

**Capillary break:** if required to limit root penetration into the underlying seal, which requires a low air-entry value (less than its thickness) and low water storage capacity.

**Seal:** a key component, which requires a low hydraulic conductivity (less than  $10^{-8}$  metres per second) and high air-entry value (to maintain saturation).

**Capillary break:** if the mine wastes are saline or potentially acid forming, to limit the uptake of contaminants into the sealing layer.

#### 4.6.3 Possible cover materials

Mine sites are often remote and possible cover materials are frequently limited to available substrate at the mine site, which include:

- topsoil or oxidised waste rock with fertiliser addition for the growth medium
- compacted (self-healing) silty, sandy clay, compacted clayey oxidised waste rock, compacted benign fine-grained tailings or compacted or slurried tailings/waste rock mixtures for the seal
- fresh waste rock with minimal fines, or quarried rock with minimal fines for the capillary break.

#### 4.6.4 Cover types

Covers evolved from landfill liner technology, with the early adoption by the minerals industry of the barrier-type cover, although unlike a liner this is within the 'active zone' (hundreds of millimetres in wet climates to several metres in arid or freeze/thaw climates). Early covers were mounded to promote rainfall run-off and minimise infiltration, and typically comprise a compacted clayey soil seal about 0.5 metres thick overlain by a growth medium as thin as 0.3 metres, which may support grasses but is quite inadequate for most terrestrial vegetation types. Barrier covers are best suited to all-year-round wet climates. They are likely to perform poorly in seasonal climates and to fail in semi-arid and arid climates. In arid climates, revegetation would be poor and the sealing layer would be prone to cracking and root penetration. Further, a compacted clay sealing layer on soft tailings or waste rock of certain types is likely to fail due to ongoing consolidation. While compacted clays may initially provide a hydraulic conductivity of less than  $10^{-8}$  metres per second or 300 millimetres per year, cracking will increase this figure by about 100-fold and they will no longer seal.

Other issues include erosion (on water-shedding) and root penetration (given the thin growth medium). A well-graded sealing material and thicker growth medium are desirable.

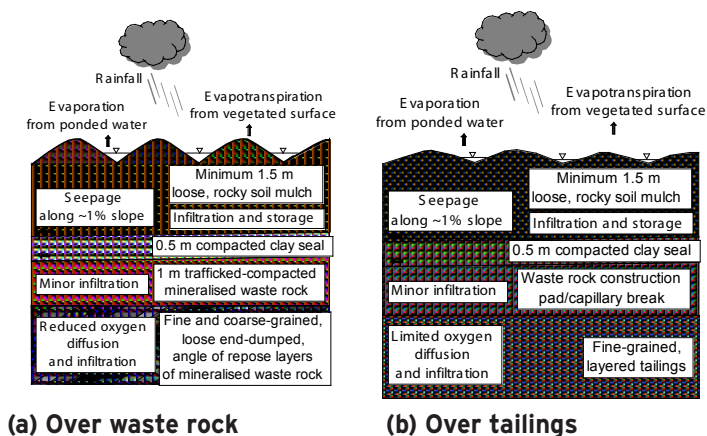
The most effective and sustainable cover system for mine wastes in a seasonal, arid or semi-arid climate is a store/release cover (Williams et al., 2006; Figures 4(a) and (b)), which mimics natural stream beds. The store/release cover system is designed to store wet season rainfall without shedding it, since this would lead to erosion of the cover, and to release stored water through the dry season through evapotranspiration, with no net wetting up or drying out of the cover from year-to-year. A store/release cover can limit percolation to one per cent of the average annual rainfall (Williams et al., 2006), effectively eliminating ongoing wetting up of the underlying mine wastes and the breakthrough of seepage to the foundation.

The essential features of a store/release cover are:

- the avoidance of low spots on the surface of the reactive wastes where infiltration through the cover might pond and lead to contaminated seepage
- a sealing layer at the base of the cover, nominally a 0.5 metre-thick compacted clayey layer (placed moist) to limit percolation through the cover in the event that the overlying store/release layer reaches breakthrough
- a rocky soil layer, placed by paddock dumping and a minimum 1.5 metres thick (depending on the rainfall patterns and physical nature of the material) to store and release excess rainfall through evapotranspiration
- smearing of the surface of the paddock-dumped mounds by a low pressure dozer to disrupt potential preferred-flow paths while retaining ponds between the paddocks to distribute surface water
- topsoiling, fertilising and seeding with native shrubs and trees initially; refertilising and seeding with grasses 12 months later to establish a sustainable diverse vegetative cover to aid water release and enhance aesthetics.

Monitored trials are generally required to develop the most appropriate cover system and selection of vegetation species for a particular mine site. The store/release cover is a dynamic system, which is very dependent on the vegetative cover.

**Figure 4: Store/release cover system**



## Case study: Store/release cover system, Kidston gold mine, Queensland

The Kidston gold mine operated in North Queensland between 1985 to July 2001. During this period the mine produced over 3.5 million ounces of gold from two open cut pits.

Kidston's climate is characterised by a three-month wet season with a nine-month dry season. The average annual rainfall is 700 millimetres, but can range between 500 millimetres and 1500 millimetres, and the average annual pan-evaporation is about 2800 millimetres. If a rainfall-shedding, barrier-type cover were used on the waste rock dumps at Kidston, the long dry season would result in desiccation of the cover and vegetation die-back. The subsequent summer storms would then cause erosion and breakthrough of the cover. The 'store/release' cover system is non-shedding, relying on storage of wet season rainfall and its release during the long dry season via evapotranspiration.

A trial store/release cover was constructed over the 23 hectares South Dump at Kidston in mid-1996, based on the schematic shown on Figure 4(a). Lysimeters were installed on the trial cover to monitor infiltration through the cover, and moisture and suction sensors were installed to monitor the moisture state of the cover itself. Over the 10 years of monitoring, infiltration has been less than one per cent of annual rainfall (although the rainfall has generally been less than the average, with a mean of 550 millimetres per year).



**Placing rocky mulch**



**Two-year old, grass-dominated vegetation**

Store/release covers have been constructed over all the waste rock dumps at Kidston, with some modifications. The tops of the paddock-dumped rocky soil mulch mounds were smoothed with a low-bearing pressure dozer to smear potential preferred seepage paths down the sides of each mound to facilitate revegetation (providing a more consistent surface texture) and for aesthetic reasons. Further, to ensure an adequate tree and shrub cover, tree and shrub seeds, in a fertiliser mix, were placed first. Grass seeds and further fertiliser were added 12 months later.



**12-month old trees and shrubs (no grasses)**



**18-month old trees and shrubs and six-month-old grasses**



**Three-year old vegetation**

## 4.7 Waste storage outer slopes

The conventional rehabilitation of waste rock stockpile and tailings storage facility outer slopes can result in a final slope with adequate geotechnical stability but inadequate erosional stability. Alternative approaches to creating stable final slopes, drawing upon surrounding natural analogues, offer the potential to produce sustainable slopes of high geotechnical and erosional stability, and improved aesthetics.

Natural hillslopes differ from constructed mine waste storage outer slopes in a number of crucial ways:

- while mine waste slopes are generally constructed and reshaped to a linear profile, natural slopes are generally concave-shaped
- armouring with rock, cemented cap rock, and vegetation are what preserve natural slopes over time
- mine waste slopes are conventionally covered with erodable fine-grained soils and an evolving revegetation cover, which may present limited resistance to erosion.

### 4.7.1 Limiting erosion off outer slopes

In seasonal, arid and semi-arid climates which do not support sufficient vegetative cover to limit erosion, mine waste storage outer slopes may require additional erosion protection. This could include a surface cover of coarse-grained benign waste rock, although some fines may be added to the mix to enhance water retention and improve growing conditions for some revegetation.

Bold gullies with generous rock covers should be constructed to handle any rainfall runoff, and contour drains that concentrate flow and generally exacerbate erosion should be avoided. Angle-of-repose final slopes, which limit the cost of slope construction, may be possible on the upper part of the slope, provided that they are disguised by bold three-dimensional profiling of the slope incorporating concave slope profiles. Concave slope profiles, which mimic natural slopes, limit the loss of sediment off the slope. Monitored trials are generally required to develop the most appropriate slope treatments for a particular mine site.



## 4.8 Topsoil management

Depending on its constituents, topsoil can serve a number of important functions such as the supply of seed and other propagules, contribution of beneficial micro-organisms, supply of nutrients, rapid development of groundcover, and the amelioration of adverse constituents in the underlying mine waste.

Most surface soils have fewer limitations to plant growth when compared with mine waste material, so the additional cost of topsoil handling is generally compensated for by greater success in the establishment of the vegetative cover. In general, topsoil should be conserved and used in the rehabilitation program when overburden material or tailings cannot support the desired post-mining land use.

### 4.8.1 Topsoil handling

A topsoil handling plan specifies topsoil sources, collecting depth, volumes and handling equipment needed, respreading depth, and any follow-up treatment (such as scarifying prior to seeding, deep ripping). The subsurface horizons of some soils possess undesirable characteristics such as high salinity and sodicity, extreme acidity and associated aluminium toxicity, or calcium deficiencies for many plants. Generally, it is preferable to strip and replace the horizons separately (double-stripping) to ensure that the nutrient-containing, microbial-containing and (sometimes) seed-containing horizon is returned to the surface.

The total depth of topsoil replaced on spoil, waste rock or tailings will be governed by such factors as the desired vegetation, the quantity and quality of the surface and subsoil available and the nature of the underlying material. A general principle is that the constructed root zone should have sufficient plant-available water to support the desired vegetation through the driest season. This can be achieved either by increasing the depth of replaced plant growth medium or, if possible, by using other materials with a high available-water capacity.

If chemical and physical tests show that the underlying material does not have major limitations to root growth, a layer of topsoil as thin as 50 millimetres will aid vegetation establishment by providing a suitable environment for seed germination, by allowing infiltration of water, and by supplying nutrients and micro-organisms. In addition, topsoil can be an important seed source when the objective is a return to native ecosystems.

Where the underlying material has adverse characteristics for root growth, the depth of topsoil required will be a function of the nature and severity of the adverse material. Applying 100 millimetres to 200 millimetres of topsoil to saline or sodic spoil will usually result in the satisfactory establishment of native species or improved pasture. However, where there is poor root penetration into the spoil, the longevity of the vegetation may be reduced by water stress during dry periods. In addition, if the hydraulic conductivity of the underlying material is low, salt movement upwards into the replaced topsoil could markedly reduce the beneficial effects of topsoil replacement. There will be less upward migration of salt when the underlying material has a moderate hydraulic conductivity. Where sulphidic waste rock is present, it should be placed deep within the pile and well away from the root zone.



Topsoil should be removed and respread with great care. Both the nature of the equipment used and the soil moisture content influence the degree of soil compaction and structural breakdown that can occur during these procedures. The combined use of a front-end loader, truck and bulldozer for the removal, transport and spreading of topsoil is the best combination to reduce compaction. For many topsoils, when moist, a fully loaded scraper can increase bulk densities above the critical values for root growth. Field trials and research may be necessary to fine-tune parameters, such as the optimal depth for collecting and respreading topsoil, as this will vary depending on seed and soil type.

#### **4.8.2 Preserving soil fertility and biota**

In cases where the objective is the re-establishment of native species, a thin layer of surface soil should be removed prior to the stripping of further soil. This is because most native seeds are concentrated in the top 50 millimetres of the soil profile. As the maximum depth of emergence of these species ranges from 30 millimetres to 100 millimetres, stripping and respreading of a surface layer greater than 100 millimetres can result in a considerable loss of potential seedlings through dilution of seeds and their failure to emerge.

During rehabilitation operations it is critical that topsoil is handled in a manner that will conserve plant diversity in the topsoil seed bank and maximise plant establishment after respreading. Specific considerations include:

- collecting topsoil at a time of year when the soil seed bank is likely to be highest
- taking into account the effects of burning vegetation prior to mining, if this is likely to influence seed survival or germinability
- respreading the topsoil directly onto an area prepared for rehabilitation, where possible
- where the amount of topsoil available is limited, it is best to spread it to a thinner depth or in strips
- any earthworks considerations, such as scarifying to 'key in' the topsoil and reduce the likelihood of it being lost through erosion—care needs to be taken not to dilute the topsoil with spoil material and to scarify across, not down, slopes
- the final topsoil surface should be freshly disturbed and suitable for direct seeding, if this is to follow.

Carefully managed topsoils also provided a supply of beneficial soil organisms not easily replaced if lost. The topsoil also contains a range of nutrients and trace elements essential to plant growth that are not normally provided in equal measure by materials (especially unweathered materials) deeper in the soil profile.

Ideally, topsoil should not be stockpiled. However, it is not always possible as mining often requires topsoil to be stockpiled adjacent to strip mining operations. Stockpiles should be constructed to minimise deterioration of seed, nutrients and soil biota, by avoiding topsoil collection when saturated following rainfall (this will promote composting), and by creating stockpiles of lower height (one to three metres). The duration of stockpiling should be minimised, as periods longer than

about six to 12 months may cause structural degradation and death of seeds and micro-organisms, especially when soil moisture content is high. Surface and subsoil material should be stockpiled separately. Seeding of the stockpile with a grass/legume mixture or native nitrogen-fixing species will assist in erosion control and reduce the loss of beneficial soil micro-organisms.

### 4.8.3 Topsoil treatments

For soils likely to be dispersive or acid generating, the use of amendments such as gypsum or lime will be required. In some cases it may be necessary to inoculate with symbiotic micro-organisms such as nitrogen-fixers and mycorrhizae. Ripping along contour will usually be required to facilitate root penetration through compacted spoil material and to reduce seed loss.

Fertilising will also be required in most cases to replace the nutrient bank lost during vegetation removal and the mining process. It is essential that the types and methods of application of macro-nutrients and micro-nutrients are carefully planned, based on detailed soil characterisation studies and rehabilitation objectives and targets. Inorganic fertilisers are most commonly used; however, organic fertilisers such as sewage sludge or vegetation mulch can be a cost-effective alternative provided care is taken not to introduce weeds and high concentrations of metals. A detailed overview of how to deal with chemical limitations to plant growth (such as nutrient deficiencies and toxicities) is given in Bell (2002).

#### Case study: Alcoa World Alumina Australia

Where topsoil contains a viable native seed source, it should be conserved for reuse following mining. This not only provides a cheap source of plants, but helps ensure that they establish in relative abundances that reflect pre-mining densities, and promotes establishment of species whose seed may be hard to obtain or difficult to germinate.



**Stripping topsoil**

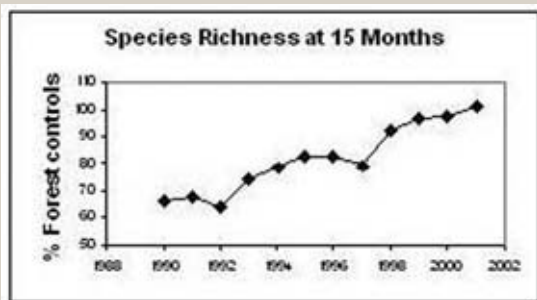


**Topsoil being respread**

The bauxite mine rehabilitation program conducted by Alcoa World Alumina Australia in the jarrah forest of south-western Australia is an excellent example of how conservation of the soil seed bank can significantly enhance the botanical diversity of the post-mining vegetation community.

After vegetation is cleared, the top 150 millimetres of soil, which contains most of the soil seed bank and nutrients, is stripped prior to mining and then directly returned to a pit about to be rehabilitated, wherever possible. Research has shown that the majority of native plant species (72 per cent) on rehabilitated areas comes from seed stored in topsoil. The importance of directly returning fresh topsoil has been demonstrated by trials comparing this technique with stockpiling. These have shown that disturbance associated with direct return of topsoil results in loss of less than 50 per cent of the seed contained in the pre-mining forest seed store; by contrast, stockpiling results in losses of 80 per cent to 90 per cent. Other aspects, such as the depth of respreading topsoil, the season when the soil is handled and the timing of seeding, are also important. Seed will not survive if buried too deep, and persists better when the soil is moved during the dry season. Also, plant establishment from seeding is greater when the seed is applied to a freshly disturbed surface. Together, the combined use of fresh topsoil return, seeding, and planting of 'recalcitrant' plants have now resulted in numbers of plant species at 15 months-of-age equal to those recorded in equivalent-sized plots in unmined forest.

For further information, see [www.alcoa.com.au](http://www.alcoa.com.au)



**Two-year-old rehabilitated bauxite mine**

## 4.9 Establishing vegetation communities

Techniques used for vegetation establishment are designed to fulfill long-term rehabilitation objectives and meet completion criteria that have been developed in conjunction with stakeholders as part of the mine closure plan. The objectives are designed to establish particular agreed land uses, with the more common being native vegetation/conservation, water quality protection, grazing, timber production and recreation. Often, the aim is to establish multiple compatible land uses.

### 4.9.1 Effects of vegetation on erosion

In general, establishment of vegetation on sloping areas is expected to reduce erosion due to reductions in run-off and in sediment detachment. The extent to which vegetation meets that expectation, however, is a function of a number of factors, including climate, vegetation type, and soil properties.

Vegetation can provide large increases in infiltration through surface protection from raindrop impact (a cause of surface seal formation), through reductions in soil water content, improvements in soil structure and structural stability, and by creation of stable macropores in the soil (Loch and Orange, 1997; Loch, 2000a, 2000b). Surface protection is largely associated with contact cover (cover in contact with the soil surface) with canopy cover (above the soil surface) becoming less effective as canopy height increases. Changes in soil structure and creation of stable macropores are influenced by rates of organic matter return to the soil and root activity.

Some vegetation communities typically those with a significant component of grass produce high rates of contact cover. In comparison, vegetation communities dominated by trees or shrubs can tend to have much lower levels of contact cover and are particularly susceptible to erosion during initial establishment.

In planning rehabilitation, it is important to identify whether vegetation is a major factor in erosion control and, if so, to determine what aspects of vegetation are critical for slope stabilisation and at what stage in the rehabilitation process. If rehabilitation relies on vegetation for erosion control, then there is typically an initial 'window of risk' that should be closed as quickly as possible (Carroll et al., 2000). In that case, species such as grasses that give rapid initial cover can be crucial and may also be important for site stabilisation following disturbances such as fire. Vigorous grass growth can hinder establishment of trees, but this is routinely managed by forestry organisations using a combination of knockdown and pre-emergent herbicides. There may also be potential to selectively place materials that favour either grass or trees to achieve the desired balance.

In general, a balanced ecosystem will contain all of the species required to provide a range of ecosystem services. Trees and shrubs are crucial components of most native ecosystems, but their contribution to erosion control particularly at some stages of the rehabilitation process may be minimal.

### **4.9.2 Controlling weeds**

Weeds may compete with local native plants. If pre-mining surveys identify the presence of problem weeds, a planned weed control program must be developed. This may involve the use of 'knock-down' and/or pre-emergent herbicides applied on a broadscale basis or by spot spraying.

If weeds are likely to be a problem, a weed or fauna management plan will be required. State or territory government agriculture departments are a useful source of information on weed control.

### **4.9.3 Defining a functional ecosystem**

In general terms, a 'functional' ecosystem is considered to be one that is:

- stable (not subject to high rates of erosion)
- effective in retaining water and nutrients
- self-sustaining.

This definition should be treated with caution. In some cases, areas infested by weeds would meet the above criteria.

In general, it is important that the goals set for site rehabilitation should clearly identify the type of ecosystem that is required, and possibly some of the ecosystem services that it is expected to provide. For example, requirements may include a high level of protection against erosion, or provide food/shelter for some particular bird or animal species. These requirements may create demands for an ecosystem that is dissimilar to those in surrounding areas.

The major issue is that the ecosystem services required should be achievable and reasonable. Considerable care should be taken to avoid framing requirements for ecosystem services too narrowly, as that can result in the target plant community identified being quite dysfunctional. Undue emphasis on 'charismatic' species should be avoided, as these species may be less important to the functioning of the ecosystem than other more cryptic species.

If goals for rehabilitation specify a particular plant community, the above three criteria provide a basis for determining whether the desired community is sustainable (functional in the long-term). However, plant communities are typically temporally and spatially variable, and assessments of functionality need to consider such variation.

### **4.9.4 Vegetation establishment**

Establishing a diverse vegetation community often requires a combination of methods. These can include the use of direct topsoil return, seeding, hydroseeding, planting of seedlings, tissue culture, transplanting and habitat transfer, and natural recolonisation. The selected combination of methods will have been developed in the rehabilitation plan, although some refinement may be necessary through trial and error during rehabilitation operations.

It may be necessary to conduct revegetation operations in several stages. For example, rapid grass establishment may be required to control erosion, while infill planting of seedlings can occur later. However, grass can compete with native species, especially those established through direct seeding. Sterile grasses can be used if those species are not part of the final land use. Care is needed to ensure that the optimal combination of methods is used to ensure that rehabilitation objectives are met.

## Seeding

Seeding is widely used across the Australian mining industry for establishing both native vegetation communities and pastures. It is often the most cost-effective means of establishing a range of plant species over a large area; however, it can be somewhat hit and miss if not carefully planned and implemented, or when unpredictable weather conditions follow seed spreading. A number of important aspects need to be taken into account to increase the chances of success when seeding.

**Seed supply:** Seed may be collected or purchased; quality control over all stages of the process is critical. Planning for native seed collection should commence at least one to two years before the seed is actually used, so that the volumes needed and collection sources can be identified. Where possible, seed should be collected locally, because it will be best adapted to the conditions and will maintain the genetic integrity of local provenances. After collection, seed will need to be cleaned and stored under conditions that will maintain maximum viability over the period of storage and minimise damage due to pests and fungi.

**Seed treatment:** Before planting, the seed of many species may need to be treated to initiate germination. Treatment methods can include heat treatment, scarification, or exposure to smoke or smoked water. Sources of information on what methods might be needed include seed suppliers, research staff and key references (such as Floradata, 2001).

In areas where rainfall is unpredictable, it may be prudent not to treat all the seed, so that some remains viable for future years. Other seed may require rhizobium inoculation or lime pelleting.

**Ecosystem succession:** If the objective is to establish a diverse, sustainable native ecosystem, then successional aspects of an eco-system must be considered. Pioneer species that readily colonise disturbed areas should be included in the seed mix; however, species characteristics of later successional stages should also be established early if experience proves this can be done successfully. The relative abundances of species will change as early colonisers die out and longer-lived species, or those that colonise later, become proportionally more dominant. High seeding rates of some early colonising species may reduce overall diversity by out-competing other species.

**Seeding rate:** The information required to determine seeding rate is not always readily available and glasshouse tests and field trials may be needed. Seed viability and germination testing can help determine what rate might be necessary to achieve a desired plant density; however, mortality of young seedlings will need to be considered. This can be high, depending on follow-up

rainfall. Higher seeding rates of ground cover species such as grasses will be necessary where erosion protection is critical.

**Seed spreading:** The actual methods of spreading seed will partly depend on what labour and equipment are available. They can include spreading by hand, helicopter, agricultural seed spreader or the bulldozer doing the ripping (this ensures that the seed is applied to a freshly disturbed surface rather than one that has developed a crust). It is important to ensure that each species is spread at the selected target rate. Some mechanical methods do not spread some seed types well.

**Timing of seeding:** The timing of seeding is critical and can vary significantly depending on local climatic conditions. Usually, the best time to seed is prior to reliable rainfall, however, rainfall is difficult to predict in much of Australia. Recent research conducted by Alcoa (Ward et al., 1996) has demonstrated the importance of applying seed onto recently spread topsoil, even if reliable rainfall is not expected for several months.

**Spreading vegetation:** In some plant communities, such as heathlands, many plant species do not readily release their seeds. These species can be reintroduced by collecting vegetation from areas being cleared for mining and returning it directly to newly rehabilitated areas where it will release its seed and provide erosion protection.

It is essential that rehabilitation is monitored given the uncertainty that still exists in relation to many aspects of seeding. Monitoring will provide the information needed to achieve continuous improvement in relation to the establishment of a diverse plant community.

### **Hydroseeding**

While it is usually more costly than conventional seeding, hydroseeding is sometimes needed to establish vegetation on steep slopes, batters and pit walls. It is usually carried out by a commercial contractor using a hydroseeding machine that pumps out a slurry of seed, mulch (such as paper mulch), binding agent and water. Successful hydroseeding requires the selection of suitable species and seeding rates, and the optimisation of mixing and application rates.

### **Planting of seedlings**

The use of hand-planted seedlings has advantages and disadvantages over direct seeding. Advantages include less wastage of seed, more accurate planting densities, better survival rates (in some but not all cases) and usually better survival where weed competition is a problem. Where rapid growth is important (for example when forestry is one of the long-term rehabilitation objectives), planting seedlings may be more appropriate than direct seeding.

Disadvantages include the higher costs associated with establishing a nursery (or buying plants from a commercial nursery), and the labour costs of hand planting. Many companies use a combination of seeding and planting, depending on the species being established.

Sources of local plants, the age and size of the seedling when planted, site preparation, the planting method, and the time of planting in relation to climatic conditions are all important for successful rehabilitation establishment using seedlings. Effective site preparation, including weed control, is critical.

Consideration should be given to:

- whether to use planting tools or machines
- plant water availability (for example by planting the seedlings in the bottom of rip-lines into which scarce rainwater will flow)
- whether to provide water to the plants by physically watering or establishing a trickle reticulation system (watering is rarely done on larger rehabilitation projects due to the prohibitively high costs and sometimes scarcity of water; however, it may have a role in small areas where establishment would otherwise be extremely difficult)
- planting seedlings on mounds where waterlogging is likely to be a problem
- providing protection from weed competition, such as using spot spraying or weed mats
- providing the correct amount and type of fertiliser
- providing protection from domestic stock, feral herbivores and native mammals
- inoculating with symbiotic microbes.

Using planting to increase botanical diversity may provide good opportunities for involving community groups, such as schools, local Aboriginal people or conservation groups. However, this approach raises two issues—safety of participants and the quality of their work. Risks associated with carrying the plants, walking on uneven ground, heat, exposure and other hazards must be identified and addressed before non-mining personnel are permitted on site. Care should also be taken to ensure that work meets the site's quality standards.



## Case study: GEMCO manganese mine, Groote Eylandt, Northern Territory

Groote Eylandt Mining Company (GEMCO) mines manganese from a number of leases on the western coastal plain of Groote Eylandt. The island has an area of 2260 square kilometres and is wholly owned by the Anindilyakwa



Aboriginal people. The mine is located in a region of Australia where knowledge of plant species is limited and successful rehabilitation can be difficult. The company therefore looked to the Traditional Owners to assist in returning their land to the way it was. In 1997, GEMCO committed to an employment and training program for the Anidilyakwan people.

The GEMCO Aboriginal Employment Strategy now involves 28 local people carrying out most rehabilitation tasks

on site, including all seed collection. This work opportunity provides them with the skills to pursue a meaningful career with either the company, the mainstream mining industry, or in the local community.

Rehabilitation of the open-pit mine started with reshaping landforms, followed by double-stripping, the return of subsoil and fresh topsoil and ripping to 1.4 metres to reduce compaction. Vegetation establishment involved, using seed and planting procedures designed to return the maximum number of plant species at densities that closely represent those found in the adjoining analogue forests. The mine's location on an island means that it is important to use locally collected seed for all revegetation work, as plants grown from these provenance seeds are better adapted to the local conditions.



About 25 species of local trees and shrubs are collected from the leases for direct seeding or the growing of seedlings for wet season planting. The quantities of seed required each season is calculated from previous research and available sites and GEMCO relies on the local knowledge of its Indigenous employees to locate the seeds and know the optimum time for collection in a particular area.

Members of the crew are now entering this information into GIS to ensure this knowledge is available for future use. Seed is collected most of the year utilising long-handled pickers, by hand, or from taller trees via elevated work platforms. All seed is cleaned to remove the husks, trash, flesh or other unwanted material which may inhibit germination.

After cleaning and drying of the seeds, data are recorded on the location, weight and date of collection, the seed is treated with carbon dioxide to reduce insect attack and is then vacuum sealed. The freshly packed seed is placed into an air-conditioned storage room to maximise long-term viability. Training is provided on all these activities to ensure they are achieved in an efficient and professional manner. The pride the members of the crew hold in their job is demonstrated by the quality of the cleaned seed, which equals any commercially supplied seed.

The Rehabilitation Section of GEMCO is also responsible for all direct seeding, some earth works preparation and the planting of seedlings during the rehabilitation season, along with all weed control across site. Several members of the team have progressed to mainstream mining and are now involved in the topsoil handling processes.

As the Traditional Owners of these lands, it is in their interest and gives them great pride to see their land returning as close to its original form as possible through their efforts.

Utilising the employee's traditional knowledge of the local plants and the seasonal changes that affect seed collection in northern Australia has meant GEMCO is able to meet its seed requirements each year and understand that people working to restore the forest see more in what they are doing than merely another job.

The Rehabilitation Section of GEMCO has made vast improvements in rehabilitation practices over the past five years, winning several awards and recognition for its best practice rehabilitation work. Maintaining increasing numbers of local Indigenous employees within GEMCO has also meant vastly improved communication between the local Traditional Owners and the company, an important factor in maintaining good relationships.

Source: Groote Eylandt Mining Company

## **Establishing recalcitrant species**

Mining companies that aim to establish a botanically diverse vegetation community often discover that some plant species are difficult or impossible to establish from seed and do not come up readily even when fresh topsoil is used. If it is important that these species be established in order to meet rehabilitation objectives, it may be necessary to use procedures such as tissue culture, cuttings or other methods.

Production of cuttings may be relatively straightforward and inexpensive, and can be a viable option for some species (for example, in rainforest environments). By contrast, tissue culture requires expensive laboratory equipment and it is usually only suitable for high-priority species such as those that are rare or fulfil key functional roles or where the priority is to establish the full range of species that occur in unmined reference sites.

In 2003 Alcoa World Alumina Australia used tissue culture and cuttings for establishing recalcitrant plants. The company used these methods to produce and plant 184 000 plants of 23 different species at an average cost of around US\$2.80 per plant in the ground.

## **Transplanting**

Transplanting whole plants or clumps of plants can be an effective means of establishing certain species in some circumstances. For example, Consolidated Rutile Limited uses this method to establish grasstrees (*Xanthorrhoea johnsonii*) in rehabilitated areas of its mineral sand mine on North Stradbroke Island in Queensland, Australia. The grasstrees are an important component of the pre-mining ecosystem and serve as valuable fauna habitat. However, they are very slow-growing and, although they are included in the seed mix, plants would take many decades to reach maturity. The company has addressed this problem by using excavators and trucks to transplant whole plants, with a 90 per cent success rate.

Transplanting can also be a cost-effective way of establishing wetland rushes and sedges. Seed can be difficult to obtain from many of these species and fluctuating water levels can result in very low success rates from seeding. Transplanting of whole clumps at intervals along the waterline can be a much more reliable way of rapidly establishing fringing vegetation.

## **Habitat transfer**

Although generally expensive and only used in specialised circumstances, habitat transfer is another option for establishing botanical diversity when other methods fail. It involves the collection and transplanting of whole clumps of plants in patches using, for example, a front-end loader. This can prove useful on a small scale where establishment of particular recalcitrant species or combinations of species is a high priority.

## **Natural recolonisation**

Natural recolonisation can, over time, result in many native plant species establishing through seed brought into a site by wind, water or fauna (such as seed in bird droppings). Companies need to understand which species will quickly recolonise in acceptable numbers and which will take much longer. There is little point in purchasing and applying seed of species that recolonise naturally within

an acceptable timeframe. However, where natural recolonisation takes a very long time, seeding or planting may be needed to establish some key species in order to meet rehabilitation objectives and stakeholders' expectations. Protection of native vegetation communities adjacent to a mine during mining operations is essential for providing a source of seed and, thereby, facilitating natural recolonisation.

## **4.10 Establishing fauna communities**

Where the aim of rehabilitation is to establish a sustainable native ecosystem, fauna habitat requirements should be taken into account. Recolonisation of fauna species to rehabilitated areas can be encouraged by the provision of suitable habitat. Establishment of vegetation communities similar to those that existed prior to mining should ensure that most species will recolonise in time. Natural fauna recolonisation is almost always preferable to physically reintroducing animals as there is no cost involved and fauna will return when the habitat meets their requirements.

### **4.10.1 Controlling problem animals**

Animals can also cause significant problems to developing rehabilitation. Grazing stock may need to be excluded by fencing during the establishment period and possibly longer. Grazing by native mammals such as kangaroos and wallabies can also be a problem and may require the use of tree guards (sleeves protecting young plants) or other methods not harmful to wildlife themselves. Introduced herbivores (such as rabbits and goats) can decimate newly established plants.

Feral predators (such as foxes and cats) present another problem to the establishment of a functional ecosystem. They can significantly reduce numbers of native mammals, thereby reducing source populations for recruitment.

A fauna management plan will be required to address these issues. State and territory government agriculture departments are a useful source of information on feral animal control.

### **4.10.2 Constructing fauna habitat**

Experience has shown that some key components of fauna species' habitat requirements may not be present in rehabilitation for many decades. Examples of how some companies have addressed these habitat deficiencies include:

- transplanting of grasstrees
- conservation and reuse of vegetation by chipping or respreading it as mulch, branches to provide shelter for small invertebrates and reptiles, erosion protection, and nutrients
- the construction of nest boxes to provide shelter and breeding habitat for many bird and mammal species
- the return of cleared timber to establish shelter in the form of logs and log piles, which ground-dwelling species shelter in or under
- construction of reptile habitat by limited use of surface boulders

- construction of perches used by raptors and other birds (who may introduce seeds)
- establishment of old dead trees ('stags') which provide hollows, crevices, exfoliating bark, all of which provide useful shelter for many smaller reptile and invertebrate species.

An Australian Centre for Minerals Extension and Research (ACMER) project entitled Innovative Techniques for Establishing Fauna Habitat Following Mining provides practical advice on methods mining companies are using to establish these and other fauna habitats (see [www.acmer.com.au](http://www.acmer.com.au)).

#### **4.11 Revegetation of non-mined areas**

Rehabilitation objectives should be developed on a whole-of-lease basis, taking into account the views of the community and other stakeholders, as well as regional land-use plans, catchment management plans, Landcare programs and other initiatives. Many mines are adjacent to degraded waterways, cleared or overgrazed land, and degraded bush isolated from other remnant bushland.

Incorporating the rehabilitation of non-mined areas into the mine rehabilitation plan can build valuable community links and significantly enhance overall environmental management outcomes. Some mines develop biodiversity offsets. These provide an excellent opportunity for integrating mine rehabilitation into regional conservation planning strategies. Protection and rehabilitation of degraded areas (forests, wetlands), establishment of corridors joining remnant vegetation, and revegetating streamside areas to enhance aquatic biodiversity are examples of biodiversity offsets that can enhance local conservation values. Other rehabilitation objectives might focus on minimising secondary impacts of the mining operation, for example, by controlling erosion which could increase downstream sediment loads, affecting water quality and aquatic biota.

As well as the standard revegetation techniques, rehabilitation of degraded areas might need to include:

- reduced grazing
- controlling feral animals
- fire management
- weed eradication
- establishment of nest boxes
- other techniques to protect water quality, enhance conservation values, and provide the sources of plant and animal recruitment over the longer term.

Local conservation and Landcare groups are a good source of information on what initiatives might prove the most cost-effective.

## **4.12 Establishment of pasture and commercial forestry**

Although much post-mining rehabilitation in Australia is now designed to produce native ecosystems, establishment of pastures suitable for stock grazing is still widely carried out, particularly in the coal mining industries of New South Wales and Queensland. Techniques used successfully for many years are summarised in Hannan (1995) and Hannan and Bell (1993). These include soil testing to determine the required rates of fertiliser and, if necessary, soil amendments such as lime. The pasture is usually established using standard agricultural seeding equipment. Recent studies have focused on determining long-term management guidelines (stocking intensities, fertilising requirements) to ensure the intended land use is sustainable (Grigg et. al., 2002).

Some mines choose timber production as one of their major post-mining land uses. Technical information on the establishment of plantations is usually readily available from relevant state and territory government departments, consultants and private forestry organisations.

Key elements to successful plantation establishment include species selection, site treatment (including deep ripping, weed control, fertilising), spacing of plants, post-establishment maintenance, monitoring and silvicultural treatment, and harvesting, milling and marketing. Rix's Creek coal mine in the Hunter Valley, New South Wales, has entered into a commercial plantation arrangement, and other mines are likely to follow.

## **4.13 Monitoring and maintenance**

Monitoring and maintenance are essential components of successful rehabilitation programs. At rehabilitation establishment, details of rehabilitation operations should be carefully documented. Recording these data serves two purposes. They enable analyses to be conducted which may be critical in helping explain initial establishment results and long-term trends. The information can also be used as an auditable checklist to confirm to regulators and stakeholders that agreed commitments have been met.

At the completion of rehabilitation establishment operations, monitoring should be carried out to assess early rehabilitation success, reveal the need for any remedial actions and determine whether rehabilitation is likely to meet long-term objectives and mine closure criteria (to the extent possible at this early stage).



## 5.0 CLOSURE

Planning for rehabilitation is undertaken in the early stages of project development and is developed in the context of the overall site closure objectives. During mining, research and site trials enable the rehabilitation program to be modified to reflect site specific parameters. At closure, the final landforms are created and the progressive rehabilitation program extended to include the remaining areas of disturbance. The most important elements of the rehabilitation program following closure are the refinement of the success criteria and the establishment of a long-term monitoring program. The objective is to demonstrate that rehabilitated areas are trending towards stable and sustainable ecosystems consistent with the defined completion criteria.

### 5.1 Consultation during mine closure

In the lead-up to mine closure, closure criteria are needed to demonstrate the success of rehabilitation. Both regulators and the local community can play an important role in the establishment of these criteria and the monitoring methods chosen to assess performance. This is particularly important if components of the closed mine site are to be utilised by the local community.

There may also be a role for the local community to play in the long-term monitoring of the success of rehabilitation. Some ecosystems may take decades to re-establish and early warning of potential problems may prevent costly maintenance programs.

### 5.2 Development of rehabilitation success criteria

There is widespread recognition from an industry, regulator and community viewpoint of the need for criteria to determine when rehabilitation is successful or complete. Success criteria for rehabilitation need to be grounded on ecological principles. Criteria based on a narrow set of vegetation indices or single chemical parameters have generally been found to be inadequate. A combination of attributes at both the landscape level and addressing more specific ecosystem properties appear to be necessary. These criteria must also be directly translated into operational monitoring programs using field survey data and maps derived from remotely sensed images. More information on this subject can be obtained from the Mine Closure and Completion handbook in this series.

### 5.3 Development of a rehabilitation monitoring program

The mining industry has supported many research programs that have presented an array of valuable techniques for assessing site stability and the sustainability, dynamics and functioning of vegetation and ecosystem processes on rehabilitated lands. There is a range of new and innovative approaches that have been demonstrated as useful in the context of measuring erosion processes and ecosystem development. For the



latter, techniques ranging from broad-scale ecological indicators at a landscape scale to determining species population and physiological responses have been used. A combination of indicators represents the most promising approach as ecosystem parameters are most effectively probed at different scales.

A sequential process for designing and implementing a rehabilitation monitoring program is described in this section. These steps would have been developed at the earlier planning stages and implemented during the progressive operational stages of the mine, but are included here for reinforcement and completeness.

### **5.3.1 Setting rehabilitation goals**

This initial phase would ideally be undertaken in conjunction with key stakeholders to discuss and agree upon the success criteria for rehabilitation. Success criteria must take into account the nature of rehabilitated areas, the post-mining land use, and any limitations or potential limitations to achieving these desired end uses. As discussed in previous sections of this handbook, these limitations could include chemical, geochemical, physical, biological or hydrological properties of the reconstructed landscapes and substrates.

There may be different success criteria for different domains or parts of the mine, such as waste rock dumps, tailings storage facilities, voids, waterways and diversions, and infrastructure areas.

If rehabilitated areas are returned to sustainable native communities containing local species, there may be suitable communities in the surrounding landscape that could act as reference sites or 'analogues' (see Section 5.3.2). However, given the nature of the mining process and the new landforms and reconstructed growth environment created, the selection of sites is not necessarily obvious. An understanding of growth media-plant-climate interactions is essential in matching reconstructed communities with suitable reference sites. For many regions of Australia, vegetation will respond largely to variations in moisture and nutrient availability, with lesser responses to other variables such as elevation or incoming solar radiation. Therefore, priority should be given to investigating the combination and interaction of a number of factors such as landscape position (run-on versus run-off areas), slope, soil (or root zone) depth and texture, surface nature and soil chemistry.

If low intensity grazing is being considered as an option for the post-mining land use, then a risk-based assessment may be required to define the key success criteria. For example, targeted research/trials may need to be conducted to address issues of sustainable carrying capacity or potential metals contamination issues.

### **5.3.2 The role of analogues**

Planning for the rehabilitation of mined landforms requires a detailed knowledge of the undisturbed condition. Baseline ecological inventories are needed to provide information on species composition and, ideally, should take into account successional stages of vegetation. Ecosystems exhibit natural flux, varying from site-to-site due to the heterogeneity of the natural environment. Therefore, a single reference system is often inadequate. Multiple reference sites should be used



to account for patch dynamics and site heterogeneity. Benchmarking needs to acknowledge and account for discrepancies caused by differences in developmental stages between young rehabilitation sites and ecologically mature reference sites.

It is important not to choose the analogues and set them up as comparative targets for the rehabilitation. This is because the major hydrological and nutritional upheavals confronting the rehabilitated communities have created an environment vastly different from the circumstances under which the nearby analogue may have evolved. The use of analogue sites is further underpinned by the assumption that such sites represent the optimal state of the ecosystem. In many cases this may not be true, given the human impacts from grazing, fire and other pre-mine activities.

While comparative standards may be clearly imperfect, there is value in setting some benchmark areas or reference sites in unmined systems so that climatic and seasonal influences that may impact on rehabilitation progression can be judged. Variations in species composition aside, the reference sites also provide a guide on the level and type of cover that is present and, as a result, the impacts of such cover on the quantity and quality of run-off water.

Observations across a variety of environments, and from landscape to micro-topographical scales, suggest that the availability of water is the key driver in the spatial distribution of vegetation communities. It has also been observed that movement of water across the landscape can influence nutrient accumulation and availability. This principle may provide the basis for understanding the potential of a reconstructed site and underpin the logical (and defensible) selection of reference or analogue communities.

### **5.3.3 Selecting monitoring parameters**

What parameters are monitored and how frequently will depend on what information the parameter provides, how sensitive its response, its correlation with known ecosystem processes and predictability, its ease (and cost) of measurement, and repeatability or degree of subjectivity. The choice of monitoring parameters is extensive but should include those parameters that are known or expected to be most limiting for successful site stability and vegetation establishment, development and sustainability.

Typically, monitoring of rehabilitation will include:

- an assessment of surface (and slope) stability
- the performance of constructed covers (where installed over mine or mineral processing wastes)
- properties of the soil or root zone media (such as chemistry, fertility and water relations)
- plant community structural attributes (such as cover, woody species density and height)
- plant community composition (such as presence of desired species, weeds)
- selected indicators of ecosystem functioning (such as soil microbial biomass).

Monitoring may also extend to surveys of selected faunal groups to assess their return (including mammals and birds), or as bio-indicators of broader ecosystem trends (ants).

An example of the parameters that could be measured at a particular site to support the site-specific criteria includes:

### **Primary**

- erosion
- soil organic carbon
- ground cover (live, litter, rock)
- vegetation species richness

### **Secondary**

- soil microbial biomass
- foliar nitrogen and phosphorus
- weed presence
- microsymbiont activity
- faunal (invertebrate) activity.

Within the above monitoring framework, a distinction has been made between primary and secondary order parameters. In this particular example, primary order parameters would be mandatory and diagnostic while the secondary order parameters are more prescriptive and inquisitive. Secondary order parameters are deemed necessary when the outcomes from measuring primary order parameters indicate that success criteria are not being met or not likely to be met. Over the timeframe of an extended monitoring program, the frequency with which the secondary order parameters are measured may well be less than for the primary order parameters.

While some plant and soil attributes are not seasonally affected, it is necessary to standardise the timing of data collection for other attributes. In the northern parts of Australia, for example, it is suggested that surveys be concentrated at the end of the wet season to coincide with optimal plant growth and other associated biological activity.

Measurement of erosion can take a number of approaches:

- trapping and measuring eroded sediment in run-off
- sampling run-off to measure sediment loads in run-off
- assessing height change in an area affected by erosion to estimate volume of removal.

The use of instrumented plots can give accurate measures of run-off and of bed and suspended sediment loads, which can be particularly useful where soil water balances and off-site movements of sediment are of concern. This approach typically gives high-quality data, but is relatively labour intensive and needs plots to be carefully located to provide meaningful data.

Sampling sediment in run-off is only relevant for considerations of suspended loads (due to the difficulty of representative samples of run-off carrying bed-load sediment) and, again, may require significant site inputs.

A range of techniques have been used to measure the volume of erosion on an area of interest. Much depends on the magnitude of erosion but, generally, approaches based on laser scanning or digital photogrammetry are able to give relatively accurate measures of volume change. Direct measurements of gully and rill volumes can be useful in some instances, but approaches using erosion pins tend to be inaccurate and quite unsatisfactory.

### **5.3.4 Selection of a monitoring approach**

Mine site environmental personnel face myriad assessment tools and techniques. They need to determine how data from these different techniques can be integrated, whether gaps exist in assessment of rehabilitation functioning, and which technique may be most appropriate for the specific site and circumstances. New techniques also need to be integrated with existing long-term data collection, and measurements at the plant level need to be integrated with measurements at the community and landscape level.

#### **Transects**

A transect-based approach is often considered suitable for data collection across many types of landscape and ages of revegetation. This methodology will adequately assess units of rehabilitated land of differing size and shape, while also assessing the inherent variability in aspect, slope and substrate composition likely within each unit. A sampling protocol using quadrats can be integrated with the transect method in order to acquire greater detail about the composition and diversity of ground cover species and other surface features important from stability and functionality perspectives.

#### **Ecosystem function analysis**

Over the past few years, a new approach to monitoring mine site rehabilitation, ecosystem function analysis (EFA), has also been employed by a number of sites. EFA, developed by CSIRO, provides a monitoring method that has been transferred from its original use in rangeland ecosystems and adapted for use in mine site situations. The method, described in Tongway (2001), consists of the primary component of landscape function analysis which uses observed soil surface features to estimate (and thereafter calculate) indices of soil stability, infiltration and nutrient cycling. Additional modules of vegetation dynamics and habitat complexity complete the package.

In a number of validation studies that have compared the informing power of the EFA approach with more quantitative methodologies, the technique has been found to be most successful where there is a relatively high degree of substrate homogeneity across the rehabilitated landscape and where rehabilitation techniques have remained fairly constant over time.

## **Remote sensing**

Remote sensing or image-based monitoring is increasingly likely to play a role in the assessment of mine site rehabilitation. Remote sensing was developed as a tool to extend field-based relationships and provides a means for focusing field studies on the whole-of-mine scale. Field data and image datasets which correlate with those field data to allow extrapolation of plot-scale measurements across the whole site are collected.

The advent of high quality airborne sensors some years ago highlighted the potential for a cost-effective, rigorous framework to plan, assess and monitor rehabilitated areas using remote sensing. Airborne hyperspectral data can offer a number of advantages over broadband remotely sensed data like aerial photographs and common types of satellite imagery (Landsat). The more recent high resolution images and spectra available from the current satellites (Quickbird and SPOT 5), provide an even greater opportunity to identify and monitor rehabilitation success.

### **5.3.5 Reviewing monitoring results**

Reporting of monitoring results on an annual or other regular basis may be a legislative requirement, although the real value of monitoring lies in the accumulation of information over the longer term. Trends in rehabilitation development with respect to reference sites can be determined and the trajectories of rehabilitation communities identified in relation to initial treatments or establishment conditions. This builds confidence in the techniques being used, not only for the company but also for the regulating authority and other stakeholders. Periodic review of monitoring information may also identify gaps in information or highlight issues that require more detailed investigation or remediation.

## **5.4 Development of a monitoring manual**

Most value from a monitoring program is obtained when harnessed with information on what happened on a particular area of rehabilitation. A record of the history of an area of rehabilitation links current performance with rehabilitation practice, such that the best approaches can be identified and problems remedied. Both sets of information (historical and current) are essential in completing the feedback loop so that continuous improvement can be achieved.

Basic information that should be documented for each area of rehabilitation will include ground preparation, use of topsoil (if any) and its source and handling, fertiliser types, rates and history, the seeding mix applied at establishment, and the timing of activities or occurrence of disturbance events such as fire. The boundaries of rehabilitation areas receiving the same treatment should also be recorded. Other information that is routinely collected on site such as rainfall, relative humidity, temperature and wind speed is also invaluable in understanding why a particular rehabilitation result was achieved.

The monitoring manual needs to set out the methods and protocols required to conduct a scientifically rigorous monitoring program of the soil and vegetation attributes of rehabilitation at mine sites. It needs to be simple and flexible enough

to be modified and refined pending outcomes of repeated implementation of the procedures and measures, and to be able to reflect any changes to rehabilitation practices that may, by necessity, be adopted over time.

Having fully documented the history of the rehabilitated site and all the underlying contributory components that led up to the completion of the seeding and planting, the manual should describe the post-establishment monitoring plan, including:

- details of transect locations, numbers of transects, and the rationale for selecting transect locations
- the locating of quadrats along transects to allow for more detailed assessment of certain parameters over and beyond point-sampling
- what should be measured along transects—where and how
- requirements on how collected samples should be stored and treated prior to analysis.

## **5.5 Lease relinquishment**

Mining companies undertake rehabilitation of disturbed ground to comply with state and territory environmental regulations and conduct monitoring of established areas to assess performance. The aim is to demonstrate the presence of a stable non-polluting landform, thereby facilitating relinquishment of the lease and release of the company from ongoing liability. Government regulators, however, may be reluctant to provide sign-off and take on the risk of future liabilities.

There are two principal areas of uncertainty. The first area of uncertainty is that the rehabilitation will fail at some time after mine closure (that is, it is non-sustainable), a risk that can be minimised by targeted research and the informed interpretation of long-term monitoring data and trends. The second area of uncertainty, and one that has received far less attention, is that the quality of rehabilitation can be spatially highly variable due to the heterogeneity of growth media resulting from the mining or mineral processing operations. Rehabilitation meeting or exceeding the set criteria in one location may well fail a short distance away. Given that rehabilitation monitoring or sampling is usually undertaken on a point basis, there remains uncertainty in the interpretation of data.

The rehabilitation plan should recognise and address variations in the underlying waste rock quality that are known to potentially impact on revegetation outcomes. This would enable the depth of the often limiting topsoil or root zone material to be varied depending on the properties of the mine waste below. Such an approach should lead to greater consistency in the quality of rehabilitation outcomes and minimise costly remedial work.

A well developed and implemented monitoring program can demonstrate that rehabilitated areas are conforming to predicted successional changes. This gives confidence to all stakeholders that the predicted outcomes will be achieved in the longer term.



## 6.0 CONCLUSION

Rehabilitation is the principal process used to mitigate the long-term impacts of mining on the environment. The objectives of rehabilitation can vary from simply converting an area to a safe and stable condition to restoring the pre-mining conditions as closely as possible to ensuring the future sustainability of the site.

Mine rehabilitation is an essential part of developing mineral resources in accordance with the principles of leading practice sustainable development. Rehabilitation is not a process that should be considered only at, or just before, mine closure. Rather, it should be part of an integrated program of effective planning and management through all phases of mine development and operations.

This handbook looks at rehabilitation through the phases of mine development, including planning, operations and closure. It outlines the principles and practices of mine rehabilitation with a focus on landform design and revegetation. Particular emphasis has been given to the restoration of natural ecosystems, particularly the re-establishment of native flora.

### Key messages

The following points summarise key messages from this handbook:

#### Planning

- develop a rehabilitation plan during the planning phase which will evolve as results from research and on-site trials become available
- ensure early characterisation of the materials to be rehabilitated to identify potential issues in time for them to be resolved
- understand the environmental externalities which have the potential to constrain rehabilitation success
- set realistic rehabilitation objectives.

#### Operations

- manage site water to minimise erosion and restrict the potential for off-site pollution
- design landforms which are safe, stable and sympathetic to the surrounding environment
- establish covers which enhance stability and protect potentially hazardous material contained within the landform
- manage topsoil to conserve valuable nutrients and enhance the viability of native seed and micro-organisms
- seek to establish flora and fauna communities which are dynamic and resilient to perturbations.

## Closure

- develop success criteria for rehabilitation which are consistent with the overall site closure objectives
- establish a rehabilitation monitoring program which measures key functional parameters of the evolving ecosystem
- demonstrate through long-term monitoring that the development of rehabilitated areas is consistent with completion criteria.

It is important to maintain engagement with key stakeholders on rehabilitation issues throughout all stages of the mining process. As well as community views, planning for rehabilitation should also incorporate pre-mining investigations including legal requirements, climatic, topographic and baseline surveys of water and air quality, flora and fauna surveys, soils and other factors. Other key aspects of the rehabilitation process include rehabilitation objectives, soil handling, earthworks, revegetation, soil nutrients, fauna return, maintenance, success criteria and monitoring.

The mining industry, indeed any industry group, is often judged by the public on the basis of its worst performers. This handbook showcases some of the excellent work undertaken by the mining industry and the minerals sector in applying the principles of leading practice mine rehabilitation. The information and case studies provided in this handbook illustrate that mining can operate on a sustainable basis.

To achieve successful rehabilitation in an environment of increasing regulatory and stakeholder expectations, will require superior outcomes developed and implemented in consultation with key stakeholders. Not only will the implementation of mine rehabilitation result in a more satisfactory social and environmental outcome, but it can also reduce the financial burden. The information in this handbook should help site managers and mine planners to develop and implement a site specific rehabilitation plan that will achieve optimal post-mining land use with the flexibility to incorporate continuous improvement through accommodating changes in methods and technology.

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## WEB SITES

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- Department of Industry, Tourism and Resources, [www.industry.gov.au](http://www.industry.gov.au)
- Leading Practice Sustainable Development Program, [www.industry.gov.au/sdmining](http://www.industry.gov.au/sdmining)
- Ministerial Council on Mineral and Petroleum Resources, [www.industry.gov.au/resources/mcmp](http://www.industry.gov.au/resources/mcmp)
- Minerals Council of Australia, [www.minerals.org.au](http://www.minerals.org.au)
- Enduring Value, [www.minerals.org.au/enduringvalue](http://www.minerals.org.au/enduringvalue)

## GLOSSARY OF TERMS

### **Abandoned mine**

An area formerly used for mining or mineral processing, where closure is incomplete and for which the title holder still exists.

### **Acid mine drainage**

Acidic drainage from mine wastes resulting from the oxidation of sulphides such as pyrite.

### **Adaptive management**

A systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. The ICMM Good Practice Guidance on Mining and Biodiversity refers to adaptive management as 'do-monitor-evaluate-revise'.

### **Analogue**

Unmined feature against which a mined feature may be compared.

### **Angle of repose**

The maximum angle from horizontal at which a given material will rest on a given surface without sliding or rolling.

### **Backfilling**

Refilling of an excavation or void.

### **Batter slope**

Recessing or sloping a wall back in successive courses.

### **Berm**

A horizontal shelf or ledge built into an embankment or sloping wall to break the continuity of the otherwise long slope for the purpose of strengthening and increasing the stability of the slope, to catch or arrest slope slough material, or to control the flow of runoff water and erosion.

### **Bund**

An earthen retaining wall.

### **Capillary break**

A layer of coarse material placed between finer-textured materials to prevent the vertical movement of water (and associated salts) by surface tension from the lower, finer-textured material into the upper finer-textured material.

### **Charismatic species**

Prominent species that may be appealing but serve little critical purpose in maintaining ecosystem sustainability.

### **Completion criteria**

An agreed standard or level of performance which demonstrates successful closure of the site.

### **Cryptic species**

Less obvious species or those that are not easily noticed.

### **Dispersive soil**

Soils that are structurally unstable and disperse in water into basic particles (such as sand, silt and clay). Dispersive soils tend to be highly erodible and present problems for successfully managing earthworks.

### **Eco-system**

A system whose members benefit from each other's participation via symbiotic relationships (positive sum relations). It is a term that originated from biology and refers to self-sustaining systems.

### **Encapsulation**

Total enclosure of a waste in another material that isolates the waste material from outside conditions (usually oxygen or water).

### **End-dumping**

The process of dumping material from the back of a dump truck. Overburden piles are constructed by backing a dump truck on the top surface of a pile to the edge of the pile, and end-dumping the waste rock over the side of the pile.

**Erosion pins**

Metal pins driven into the soil to provide a benchmark and used to estimate magnitude of surface lowering by erosion at that point. As erosion on hillslopes is highly spatially variable, a large number of pins are needed if an accurate estimate of erosion is to be obtained. (Generally the number of pins used is highly inadequate.) This approach is more suited to assessing growth of gullies or large rills, where erosion is strongly localised.

**Final void**

The remnant open pit left at mine closure.

**Footprint**

The surface area covered by the mine and its associated infrastructure.

**Functional ecosystem**

An ecosystem that is stable (not subject to high rates of erosion), effective in retaining water and nutrients and is self-sustaining.

**Hydroseeding**

Spraying a mixture of paper or straw mulch, containing seed, fertiliser and a binding agent, onto a slope which is too steep or inaccessible for conventional seeding techniques.

**Key in**

Construction of a back-filled trench to reduce seepage or improve the stability of an earthen embankment.

**Kinetic testing**

Dynamic testing of acid generation, including the effect of reaction time.

**Leading practice**

Best available current practice promoting sustainable development.

**Local provenance**

Plants whose native origin is close to that where they are going to be planted (for example in the same local area).

**Macropores**

Large void space between coarse-grained particles.

**Moonscaping**

A technique using dozer blades to scallop a pattern which helps prevent erosion.

**Overtopping**

Water or tailings slurry breaching the top of the containment structure.

**Paddock-dumping**

Truck dumping over a flat surface.

**Pioneer species**

The first species to colonise an area of disturbance.

**Propagule**

Any structure having the capacity to give rise to a new plant, whether through sexual or asexual (vegetative) reproduction. This includes seeds, spores, and any part of the vegetative body capable of independent growth if detached from the parent.

**Ravelling**

The flow and segregation of coarse-grained waste rock on end-dumping over an angle-of-repose slope.

**Reactive waste**

Waste that reacts on exposure to oxygen.

**Recalcitrant species**

Species that are difficult to re-establish.

**Rehabilitation**

The return of disturbed land to a stable, productive and self-sustaining condition, after taking into account beneficial uses of the site and surrounding land.

**Relinquishment**

Formal approval by the relevant regulating authority indicating that the completion criteria for the mine have been met to the satisfaction of the authority.

**Remnant vegetation**

Native vegetation remaining after widespread clearing has taken place.

**Rip-rap**

A loose assemblage of broken rock placed to protect soil from the forces of erosion or from movement due to excess hydrostatic forces.

**ROM pad**

The stockpile of freshly mined ore used to feed the mill and process plant.

**Scarification**

The process of disrupting a seed coat to encourage germination.

**Slurry**

A finely divided solid which has settled out from thickeners.

**Social licence to operate**

The recognition and acceptance of a company's contribution to the community in which it operates, moving beyond meeting basic legal requirements, towards developing and maintaining the constructive relationships with stakeholders necessary for business to be sustainable. Overall it comes from striving for relationships based on honesty and mutual respect.

**Sodic soil**

Soils containing sodium as a significant proportion (commonly greater than six per cent) of their total exchangeable cations. Sodic soils tend to have poor drainage due to poor soil structure.

**Static acid base accounting**

Balance between complete acid and alkaline reactions.

**Stope**

Underground mine opening or void.

**Store/release cover**

Cover suited to seasonal, moisture deficit climates that stores rainfall infiltration during the wet season and subsequently releases it through evapotranspiration during the dry season.

**Edge Effect**

The effect of one habitat upon another along the boundary between the two habitats. A cleared habitat may exert an impact along its boundary with an uncleared habitat by increasing the penetration of sunlight and wind.

**Supernatant**

Water that bleeds off the top of deposited tailings slurry.

**Tailings storage facility**

An area used to confine tailings; its prime function is to achieve solids settling and improve water quality. It refers to the overall facility, and may include one or more tailings dams.

**Tissue culture**

A method of asexual propagation used to produce clones of a particular plant in large quantities.

**Trajectories of rehabilitation communities** Trends in the rehabilitation as it develops over time.

**Waste rock**

Uneconomic rock extracted from the ground during a mining operation to gain access to the ore.

**Wetting up**

Rainfall infiltration into mine waste, which progresses downward.