Australian Government

MINE REHABILITATION

Leading Practice Sustainable Development Program for the Mining Industry

September 2016

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Support for the LPSDP was provided by the Australian aid program administered by the Department of Foreign Affairs and Trade due to the reports' value in providing practical guidance and case studies for use and application in developing countries.

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

September 2016.

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CASE STUDIES:

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FOREWORD

The *Leading Practice Sustainable Development Program for the Mining Industry* series of handbooks has been produced to share Australia's world-leading experience and expertise in mine management and planning. The handbooks provide practical guidance on environmental, economic and social aspects through all phases of mineral extraction, from exploration to mine construction, operation and closure.

Australia is a world leader in mining, and our national expertise has been used to ensure that these handbooks provide contemporary and useful guidance on leading practice.

Australia's Department of Industry, Innovation and Science has provided technical management and coordination for the handbooks in cooperation with private industry and state government partners. Australia's overseas aid program, managed by the Department of Foreign Affairs and Trade, has co-funded the updating of the handbooks in recognition of the central role of the mining sector in driving economic growth and reducing poverty.

Mining is a global industry, and Australian companies are active investors and explorers in nearly all mining provinces around the world. The Australian Government recognises that a better mining industry means more growth, jobs, investment and trade, and that these benefits should flow through to higher living standards for all.

A strong commitment to leading practice in sustainable development is critical for mining excellence. Applying leading practice enables companies to deliver enduring value, maintain their reputation for quality in a competitive investment climate, and ensure the strong support of host communities and governments. Understanding leading practice is also essential to manage risks and ensure that the mining industry delivers its full potential.

These handbooks are designed to provide mine operators, communities and regulators with essential information. They contain case studies to assist all sectors of the mining industry, within and beyond the requirements set by legislation.

We recommend these *leading practice* handbooks to you and hope that you will find them of practical use.

Senator the Hon Matt Canavan

Minister for Resources and Northern Australia

The Hon Julie Bishop MP

Minister for Foreign Affairs

1.0 INTRODUCTION

Mining has the potential to affect the environment and communities throughout the life cycle of a project. Those impacts, whether direct, indirect or cumulative, make many project developments potentially sensitive for regulators, local communities, investors, non-government organisations (NGOs) and employees. Obtaining access to land for the purposes of mineral extraction is therefore becoming increasingly difficult and has developed into a key risk for the industry. To ensure continued access, Australian mining companies must demonstrate their commitment to sustainable development to regulators and their various stakeholders. Although mine-site rehabilitation is a legal obligation for all mining projects in Australia, it is also an activity in which the industry can clearly demonstrate its sustainable development commitment to its key stakeholders.

This handbook addresses mine rehabilitation, which is one theme in the Leading Practice Sustainable Development in Mining Program. 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 its operation. Leading practice rehabilitation starts at the very beginning of the mining project and continues through to mine closure and lease relinquishment. It must take account of all relevant site, local, regional, national and even international aspects.

The primary audience for this handbook is management at the operational level—those who are responsible for implementing leading practice at mining operations. It is also relevant to people with an interest in leading practice biodiversity management in the mining industry, including environmental officers, mining consultants, governments and regulators, non-government organisations, neighbouring and mine communities, and students. All users are encouraged to work together in partnership, taking up the challenge to continually improve the mining industry's standards of rehabilitation, as part of its sustainable development performance. Improved performance can be achieved through applying the principles outlined in this handbook.

This handbook outlines the key principles and procedures now recognised as leading practice for planning, implementing and monitoring rehabilitation:

- understanding the importance of rehabilitation and its business case for the mining sector (Section 2)
- establishing rehabilitation objectives, targets and success criteria (Chapter 3)
- planning to rehabilitate through engaging with stakeholders, setting objectives and completion criteria, and establishing rehabilitation baselines (Chapter 4)
- integrating and implementing rehabilitation plans during the life of the operation (Section 5)
- monitoring and reporting mine-site rehabilitation performance (Section 6).

The handbook has not been written in isolation and should be read in conjunction with the other leading practice handbooks, specifically those dealing with:

- groundwater and surface water management and monitoring
- acid and metalliferous drainage
- tailings management
- biodiversity
- closure planning
- community engagement
- monitoring.

The handbook is intended to be an overview guide only and is neither prescriptive nor comprehensively detailed. Environmental managers and practitioners are encouraged to access and use the technical material referenced throughout the handbook for more in-depth information.

2.0 THE IMPORTANCE OF MINE REHABILITATION

Key messages

- Rehabilitation is an integral component of a mining company's sustainable development strategies.
- Rehabilitation is invariably a key performance indicator against which the company's environmental performance is judged.
- Poorly rehabilitated mines leave significant legacy problems for all elements of society—governments, communities and companies.
- Failure to plan and to start rehabilitation early in the life of the operation may create an obstacle to building the knowledge and capacity necessary to deliver a sustainable outcome that meets agreed success criteria.

2.1 What is rehabilitation?

This handbook adopts the following definition of rehabilitation:

> Rehabilitation comprises the design and construction of landforms as well as the establishment of sustainable ecosystems or alternative vegetation, depending upon desired post-operational land use.

Mine site rehabilitation should be designed to meet three key objectives:

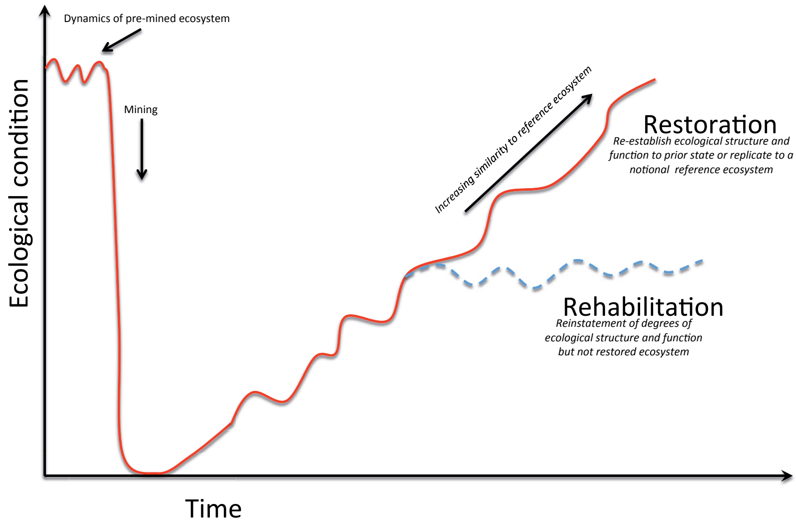
1. the long-term stability and sustainability of the landforms, soils and hydrology of the site
2. the partial or full repair of ecosystem capacity to provide habitats for biota and services for people (WA EPA 2006)
3. the prevention of pollution of the surrounding environment.

Various terms have been used to describe the repair of land disturbed by mining and other forms of land use, including rehabilitation, reclamation, reconstruction, repair, restoration and revegetation. For consistency with the National Standards for the Practice of Ecological Restoration in Australia (Standards Reference Group SERA 2016), the two main terms used in this handbook are *rehabilitation* and *restoration*.

While the importance of strict definitions for terms such as rehabilitation and restoration has been questioned, there is benefit in having a functional understanding of the differences between the two processes. That understanding can also help to achieve more consistency in policy, legislation and regulation governing environmental repair.

Rehabilitation and restoration trajectories are shown in Figure 1, in which the Y-axis represents ecological condition and the curves show change in that condition over time for both.

Figure 1: Hypothetical ecosystem development incorporating state and transition concept (modified from Grant 2006 and Doley & Audet 2014) to help show differences between rehabilitation and restoration (from Standards Reference Group SERA (2016).



Source: after Bradshaw (1987).

Following mining, there is typically a regression in structural and functional complexity. Rehabilitation aims to reinstate ecosystem functionality and land productivity, although it will probably assume a different land-use and species composition from the original ecosystem. The new ecosystem may be simpler in structure than the original but more productive, such as when a woodland is replaced with a plantation or grazing land. Alternatively, the new ecosystem can be simpler but less productive in the form of a hybrid or novel ecosystem, such as planted eucalypts over a weed–grass understorey.

In contrast, restoration has the more ambitious aim of re-establishing ecosystem structure and function to an image of its state before disturbance, or of replicating a desired reference ecosystem. Restoration aims to re-establish an ecosystem that develops along a successional pathway so that it assumes a similar, but not necessarily identical, structure, function and composition to the original ecosystem.

Importantly, as ecosystems develop, definitions might also morph or develop over time. For example, a rehabilitated ecosystem or landscape may progress into a near-natural, restored ecosystem. Conversely, ecosystems that are ostensibly being restored may be neglected because of a lack of management intervention and may be more representative of rehabilitation.

2.2 Rehabilitation in the context of sustainable development

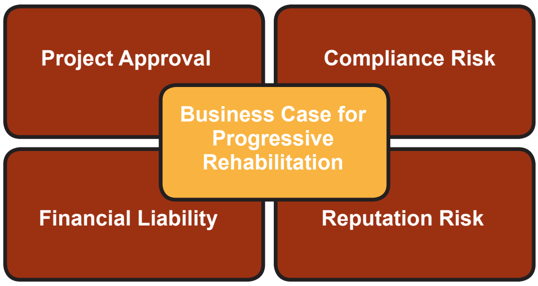
Mining is a temporary land use (although some mines can have very long lives), and each operation is expected to close at some point in the future. The closure of the operation generally occurs when the resource is depleted or when the cost of production exceeds returns. Closure therefore provides opportunities for land disturbed by mining to be rehabilitated to one or more sustainable post-mining land uses (DEHP 2014).

For mining companies in Australia, rehabilitation should be an integral component of their sustainable development strategies. Rehabilitation is invariably a key performance indicator against which companies' environmental performance is judged. Poorly rehabilitated mines provide significant legacy problems for all elements of society—governments, communities and companies.

2.3 The business case for rehabilitation

A number of factors define the business case for mine-site rehabilitation (Figure 2). Gaining access to land increasingly requires companies to demonstrate their commitment to land-use stewardship. Rehabilitation is invariably a key performance indicator. Regulatory trends are such that achieving leading practice rehabilitation will, in the short to medium term, be a competitive advantage; over the longer term, it will be the minimum qualification for obtaining land access. Failure to demonstrate a strong commitment to land-use stewardship, particularly successful rehabilitation, can lead to approval delays and, in the worst case, total loss of development opportunities.

Figure 2: The business case for mine-site rehabilitation



2.3.1 Progressive rehabilitation

Failure to start rehabilitation early in the life of the operation (or in the later stages of project development) may create an obstacle to building the knowledge and capacity necessary to deliver a sustainable outcome that meets agreed success criteria. At worst, initiating closure operations when the site has not developed the skills, equipment and necessary technical knowledge to successfully carry out a large rehabilitation program can result in very poor outcomes requiring very costly remediation, and with greatly reduced probability of successful closure.

Successful rehabilitation requires a continuous improvement focus, based on site-specific knowledge, research and monitoring. Opportunities and threats should be identified early so that mining operations do not reduce rehabilitation options. Thus, delayed investment leads to delayed relinquishment beyond the operational life of a mine, adding to cost and, in some cases, the retention of a liability for years longer than necessary.

2.3.2 Compliance risk

A failure to meet regulatory expectations could attract increased scrutiny, leading to additional restrictions on companies, higher compliance costs and possibly legal costs. In a worst-case scenario, it could lead to the loss of the company's social licence to operate and limit its future access to resources.

2.3.3 Financial liability

Rehabilitation is a critical part of mine closure planning, and effective and early planning helps to minimise rehabilitation costs. Progressive rehabilitation can also provide an early indication as to whether site closure objectives are realistic and achievable. From a legislative perspective, state governments are increasingly reinforcing the critical linkage between rehabilitation and closure through requirements for sites to develop life-of-mine or mining operations plans (DTIRIS 2013).[1]

2.3.4 Reputational risk

A record of poor rehabilitation can lead to reputational damage among regulators and external stakeholders. This may manifest itself in project approval delays, more stringent permit conditions or even the loss of the company's social licence to operate. In contrast, a proven track record of quality rehabilitation outcomes has the potential to be a point of differentiation and define the company as a development partner of choice for regulators and local communities.

2.3.5 Rehabilitation and ecosystem services

The Society for Ecological Restoration recommends the use of nine ecosystem attributes for measuring restoration (rehabilitation in the mining context) success (SER 2004):

- similar ecosystem diversity and community structure to those of reference sites
- the presence of indigenous species
- the presence of functional groups necessary for long-term stability
- the capacity of the physical environment to sustain reproducing populations
- normal functioning
- integration within the landscape
- the elimination of potential threats
- resilience to natural disturbances
- self-sustainability.

In a 2005 study, Ruiz-Jaen and Aide concluded that few restoration studies had the financial resources to monitor all of those attributes. In their review of 68 published studies, they found that most assessed measures can be categorised as one of three types of measure: diversity, vegetation structure and ecological process attributes. Of the three, they found that ecological processes are rarely measured due to their slower recovery when compared to diversity or vegetation structure.

The fragmented nature of mine-site rehabilitation also needs to be considered when considering the use of ecological processes and ecosystem services as attributes of criteria for monitoring success. In certain circumstances, it may not be possible to use ecosystem service attributes to monitor rehabilitation success at small and discrete rehabilitation sites.

1 The *Mine closure* leading practice handbook deals with this in detail.

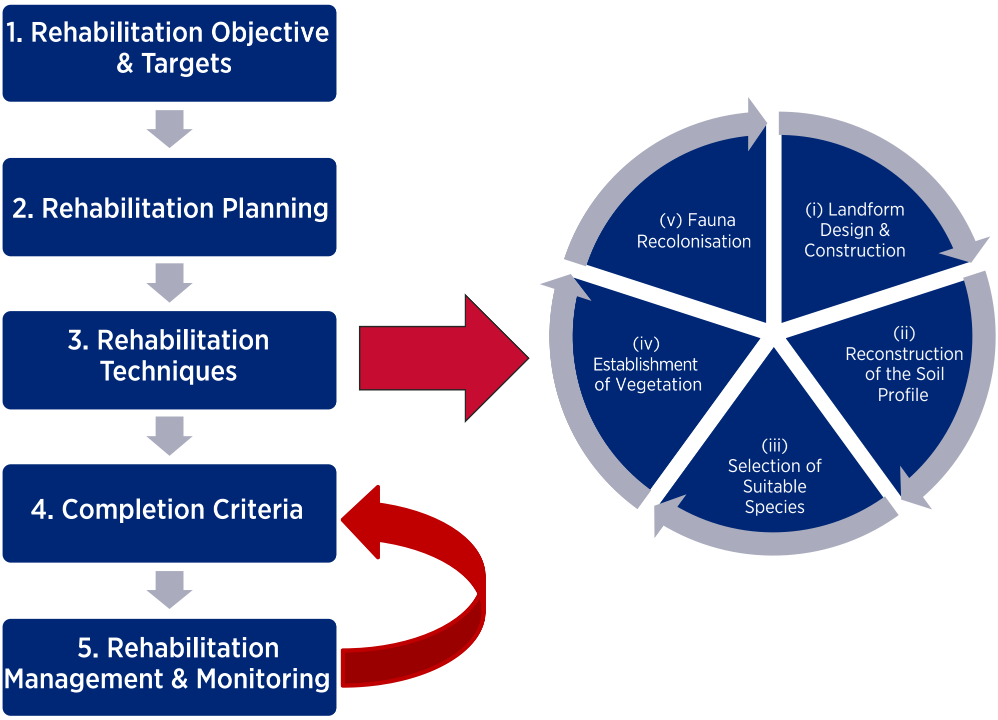
3.0 REHABILITATION SUCCESS

Key messages

- Rehabilitation is a costly process and therefore needs to be carefully planned and implemented.
- SMART targets and objectives are essential for rehabilitation success.
- The development of rehabilitation success criteria must involve stakeholders (both community and government) in their development and assessment.

Rehabilitation is a costly process, and opportunities to repeat unsuccessful rehabilitation works are often limited, so it is important that work consistently achieves acceptable outcomes. In order to be successful, rehabilitation programs must follow a number of steps (Figure 3).

Figure 3: Stages of rehabilitation planning and implementation



3.1 Rehabilitation targets and objectives

As for all projects, it is critical to establish targets and objectives for rehabilitation works to guide planning and execution. At the outset, clearly defined objectives are essential to inform stakeholders and to provide a basis for stakeholder input and consultation. Success criteria both provide greater detail on rehabilitation objectives and give confidence that the rehabilitation works will achieve the full range of objectives, including stability and sustainability.

General rehabilitation objectives may vary considerably between sites, or even within a site. The site's objective may involve:

- the restoration or reclamation of the area so that the pre-mining conditions are replicated (75% of mines in Australia use native plant species because the establishment of native ecosystems gives the greatest chance of self-sustainability)
- rehabilitation to improve the pre-mining conditions (for example, some Hunter Valley coalmining rehabilitation increases the livestock carrying capacity of the land)
- rehabilitation to a new landform, land capability or final land use (golf courses, wetlands, plantations, housing subdivisions and recreational playing fields have all been established on old mining sites).

The management of pollution as well as other health and safety risks needs to be an objective of all rehabilitation activities (see Case study 1).

Case study 1: Anglo American's rehabilitation objectives for coalmines in Queensland and NSW

Anglo American Coal Australia's general rehabilitation objective is:

> To rehabilitate areas disturbed by mining activities to a condition that is safe, stable, non-polluting and sustainable that considers stakeholder expectations.

This general rehabilitation objective is complemented at all sites by more specific objectives developed on a site-by-site basis. Those objectives focus on the sustainability component of the general objective and link with mine closure plans.

The two major land uses that are relevant to Anglo American's operations are low-maintenance native vegetation and grazing, which are often included in sites' environmental authorities or consent conditions.

In defining rehabilitation objectives, analogue or reference sites can be useful in determining the composition, structure and function of the desired rehabilitation outcome. Importantly, rehabilitated sites will never be exactly the same as analogue sites and, in some respects, may be quite different. However, this should be seen not as a reason to not use analogue sites, but rather as an important reason for clearly defining the limitations of the approach. Each site needs to define specific rehabilitation objectives for each land-use type. An example of a specific rehabilitation objective for native vegetation would be:

> To rehabilitate defined areas to a low-maintenance native vegetation, with composition, structure and function based on a relevant analogue ecosystem (or agreed representative site), and with a stable landform and self-sustaining vegetation cover.

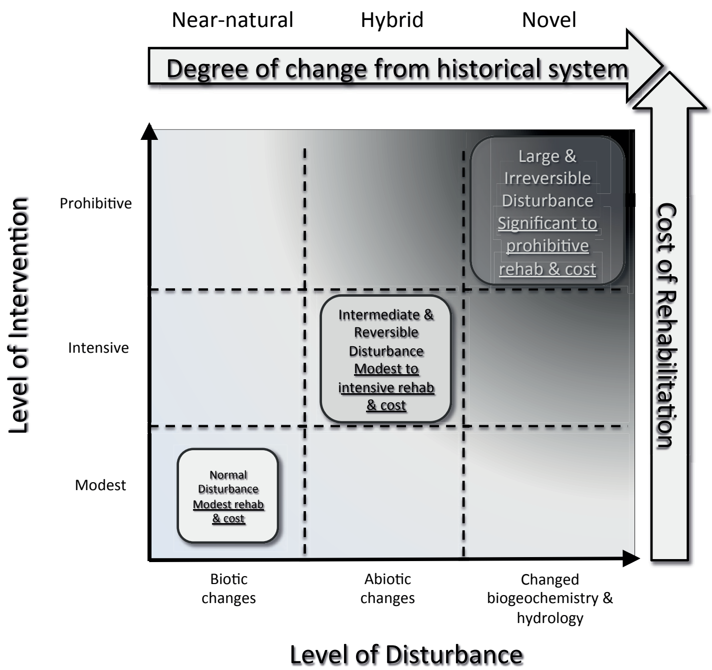
An example of a specific rehabilitation objective for grazing would be:

> To rehabilitate defined areas to a grazing land use with a carrying capacity equivalent to non-mined areas, and with a stable landform and self-sustaining vegetation cover.

The scale and type of mining impacts (for example, subsurface removal during bauxite mining versus open-cut coal or metal mining), together with local environmental factors, affect a mine site's ability to achieve its rehabilitation targets and objectives. Many mines in Australia are in regions where the delivery of productive agricultural landscapes or vegetation similar to pre-existing ecosystems is difficult or impossible (Doley & Audet 2016; Mulligan 1996; Tongway & Ludwig 2011). This is particularly pronounced where physical resources are limited (for example, soil physical or nutritional quality, rainfall availability and predictability), such as in semi-arid landscapes (Audet et al. 2013; Vickers et al. 2012).

Combined with the scale of the disturbance due to the resource extraction method, such local environmental factors greatly influence the likelihood that rehabilitation efforts will be successful (Doley & Audet 2013) (Figure 4).

Figure 4: Relationship between the level of disturbance and the level of realistic intervention, indicating the degree of change from the historical ecosystem and corresponding financial costs of rehabilitating affected lands



Source: modified from Doley & Audet (2013), Jackson & Hobbs (2009), Seastedt et al. (2008).

Within any mine site, there are different areas that require different rehabilitation approaches and methodologies. These are commonly referred to as 'domains' and include pits, waste rock dumps, tailings storage facilities, roads, infrastructure, topsoil stockpiles, stream diversions, ramps and undisturbed areas. Different rehabilitation objectives, prescriptions and success criteria are likely to be needed for the different domains. Rehabilitation of some domains (such as infrastructure and roads) cannot occur until the end of the life of the mine. However, other domains (such as waste rock dumps and tailings dams) can be rehabilitated progressively during the operational phase.

The pre-mining condition of the land provides a guide to the options available for the post-mining land use, which should be included in the rehabilitation objective. Documentation of the state of the land before mining also provides a benchmark against which the eventual success of rehabilitation may be judged, so it is in the mining company's best interests to record as much information as possible.

It is important to distinguish between land use and land suitability. The latter is a measure of the capacity of the land for various types of land uses (such as conservation, cropping or grazing). The current use of the land may be appropriate to its suitability for defined uses or it may be inappropriate, leading to land degradation through erosion, weed infestation or loss of organic matter and fertility. If the land is severely degraded, then it may be appropriate to consider alternative post-mining land-use options, such as golf courses, residential developments, parkland areas or industrial areas.

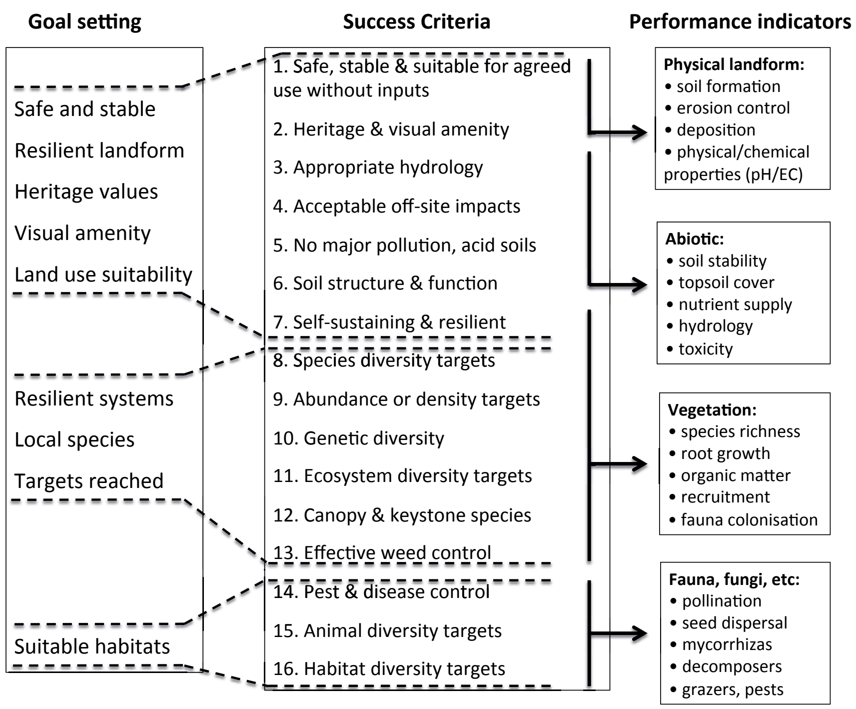
3.2 Rehabilitation success criteria

In mine-site rehabilitation, success criteria are defined as the qualitative or quantitative standards of performance used to measure the success or otherwise of rehabilitation actions needed for the closure of the site and the relinquishment of the mining lease (WA EPA 2006). They represent milestones in the biophysical processes of rehabilitation that provide a high degree of confidence that the rehabilitated site will eventually reach the desired sustainable state (the rehabilitation objective).

The company is looking for criteria that indicate the success of its rehabilitation work and enable it to determine when its liability for the area ceases. Governments also want successful rehabilitation to ensure that they are not inheriting an ongoing liability, or that a liability will be transferred to private landowners or the next land-user in the case of public lands.

The setting of goals for rehabilitation, building achievable success criteria and matching performance indicators (see Section 6.4) need to be tightly linked to bring long-term success (Figure 5).

Figure 5: The relationship between rehabilitation goal setting, success criteria and performance indicators



Note: Not all of the criteria apply to every site, but the level of disturbance and the level of realistic intervention need to correspond to the site-specific conditions, as demonstrated in Figure 4.
Source: modified from WA EPA (2006).

Another aspect of setting success criteria for rehabilitation goals is an acknowledgement that rehabilitated areas develop over a number of years and that specific growth stages and associated success criteria may need to change over time. Therefore, the use of progressive success criteria as opposed to only final success criteria allows for progressive acceptance from the regulator and for corrective management actions early on in the rehabilitation to remedy any issues that may become apparent. One leading practice example of sound success criteria is from Alcoa (Case study 2).

Case study 2: Alcoa's bauxite mine completion criteria

Alcoa began developing completion criteria for its bauxite mining operations in Western Australia in the 1990s. Prescriptions for rehabilitation used before 1988 (early era) were different from those used in subsequent years (current era), which meant that two sets of criteria were needed. The first set of criteria for current era rehabilitation was approved in 1998 and for early era rehabilitation in 2002. Alcoa is committed to regularly reviewing the criteria for current era rehabilitation to be able to integrate improvements in knowledge (for example, arising from Alcoa's research and monitoring programs), new technologies and changes in stakeholder expectations. Two revisions have been completed to date.

The criteria were designed to reflect the guiding principles of meeting rehabilitation objectives, landscape integration, sustainable growth, resilience and land management integration. Rehabilitation is assessed during various stages of the rehabilitation operations and during the early and later years of ecosystem development. Early assessment for selected criteria enables corrective actions to be carried out effectively and cost-efficiently. One of the 30 completion criteria for rehabilitation established from 2016 onwards is detailed in the table below. An adequate stocking of overstorey trees of the two dominant forest species, jarrah *(Eucalyptus marginata*) and marri (*Corymbia callophylla*), is assessed within the first year after establishment (at 9 months), allowing replanting, reseeding or thinning (by herbicide application) to be carried out at an early stage. Alcoa makes the assessment internally, and the Western Australian Department of Parks and Wildlife does a field inspection and audit on an annual basis. For the combined stocking requirement, both a minimum and a maximum limit apply in an effort to balance timber production objectives with water, conservation and other forest values.

One of the 30 completion criteria for rehabilitation established from 2016 onwards (3. Early establishment—first 5 years; 3.1 Vegetation establishment)

CRITERIA AND INTENT	GUIDELINES FOR ACCEPTANCE	STANDARD	CORRECTIVE ACTION
3.1.1 Establishment of overstorey (a) The overstorey stocking of both jarrah and marri to meet standards.	Rehabilitated areas must have a stocking rate which will meet designated land uses. Alcoa must submit 9-month monitoring data to DPaW annually. DPaW must review and advise Alcoa of acceptance or request corrective actions. Establishment of overstorey that has achieved the standard will be deemed acceptable unless DPaW writes to Alcoa within three months of self-certification unless otherwise agreed.	The average number of stems/ha within a pit (9-month monitoring data): • Min.: 600 eucalypt stems/ha (including min. 150 jarrah stems/ha and min. 200 marri stems/ha) • Max.: 1,400 eucalypt stems/ha • Target: 1,000 eucalypt stems/ha (except haul roads and pits < 2 ha). No rehabilitated sites (>2 ha in size) have areas >0.5 ha (as identified from either 9-month monitoring or subsequent review of aerial imagery at ~5 yrs of age) with <100 stems/ha.	Alcoa to provide documentation and advice to DPaW where self-certification has resulted in outcomes that do not meet the standard. Rehabilitated areas that do not meet the minimum standard will be replanted or reseeded by Alcoa with minimal delay (once conditions are suitable) to enable the minimum standard to be achieved. Rehabilitated areas that exceed the maximum standard will be inspected by DPaW and may be thinned by Alcoa to reduce tree density back to the identified acceptable range, as required.

DPaW = Western Australian Department of Parks and Wildlife.

A copy of the full completion criteria is available at http://www.dsd.wa.gov.au/alcoa’s-bauxite-mine-rehabilitation-program.

Later assessments indicate whether rehabilitation is exhibiting sustained growth and development and ensure that regional-scale requirements, such as the reinstatement of access tracks needed for future forest management, are complete. Applications for relinquishment are planned for sub-regions rather than for individual rehabilitated pits. Assessments follow an agreed process of inspections, the completion of any remedial works and final sign-off. In 2005, a total of 975 ha of rehabilitated land at Alcoa’s now decommissioned Jarrahdale mine site was handed back to the state government and a certificate of acceptance was issued to Alcoa. This was the first large-scale relinquishment of rehabilitated land by a mining company in Australia. A certificate of acceptance was issued for a further 380 ha of mine rehabilitation at Jarrahdale in 2007.


CERTIFICATE OF ACCEPTANCE

The Department of Conservation and Land Management issues this Certificate of Acceptance to Alcoa World Alumina Australia on recommendation from the Mining and Management Program Liaison Group. The certificate is for 975 hectares of State forest within the Wungong Catchment and is referred to as **Jarrahdale Area One,** the area coloured green on the map marked "A" attached to this certificate.

The Minister for the Environment's *Statement* 390 of 1995 (pursuant to Part IV of the Environmental Protection Act 1986). Procedure 4(6) Final rehabilitation completion criteria states.... *"where areas have met all appropriate criteria, a certificate of acceptance will be supplied to the proponent by the Department of Conservation and Land Management, on behalf of the State"*

Alcoa World Alumina Australia has met all of the appropriate criteria required by CALM for rehabilitating Jarrahdale Area One, which was cleared for bauxite mining purposes under the Alumina Refinery Agreement Act 1961.

The issue of this Certificate of Acceptance is formal acknowledgement that Alcoa World Alumina Australia has no residual liability or management responsibility for **Jarrahdale Area One** henceforth.

Keiran McNamara
Executive Director
Department of Conservation and Land Management
Dated 8th day of November 2005

Certificate of acceptance issued for part of Alcoa's Jarrahdale mine site.

Further reading: Elliott et al. (1996); Grant (2007); Grant & Koch (2007).

The first step in developing success criteria is to define guiding principles that will allow more specific site criteria to be developed. The principles should include items such as the following:

- Rehabilitation objectives are met.
- Landforms are integrated into the surrounding landscape and are non-polluting.
- Rehabilitation exhibits sustained growth and is resilient.
- Rehabilitation can be integrated with surrounding areas and requires no additional ongoing resources.

The second step is to define the time categories under which each success criteria principle needs to be assessed. It is critical that each principle is checked at multiple times. Possible time categories for success criteria are:

- development and mining
- rehabilitation process
- early development (0–5-year-old rehabilitation)
- established rehabilitation (>5-year-old rehabilitation).

The third step is to begin developing site-specific success criteria under each guiding principle at each time category. This should commence with a review of the rehabilitation requirements outlined in the site permit. Criteria should be developed for each permit requirement under the relevant principle and time category.

The fourth step is to define the site-specific rehabilitation success criteria. Each criterion should have the following elements:

- criteria and intent
- guidelines for acceptance
- accepted standard
- potential corrective actions.

This process for the development of success criteria has been used successfully for bauxite mining in the jarrah forest of Western Australia, where more than 3,000 ha of rehabilitated land has been issued with a completion certificate. A similar process has been proposed for the Hunter Valley in NSW and Bowen Basin in Queensland (Nichols 2004).

3.3 Rehabilitation guidelines

Most Australian states have guidelines for conducting mine rehabilitation, particularly those states with more intensive mining activities. Examples of more detailed guidelines for rehabilitation and mine closure include:

- Western Australia: *Rehabilitation of terrestrial ecosystems: guidance for the assessment of environmental factors, Western Australia* (WA EPA 2006) and *Guidelines for preparing mine closure plans* (WA EPA 2015)
- Queensland: *Rehabilitation requirements for mining resource activities (EM1122)* (DEHP 2014)
- New South Wales: *ESG3: Mining Operations Plan (MOP) guidelines* (DTIRIS 2013).

Non-government guidance documents and handbooks include Mulligan (1996); Nichols (2004, 2005); Tongway & Ludwig (2011).

For mine sites where radioactive materials may be present and constitute a hazard (such as uranium mines or some mineral sands mines), the management of radiation will be a key consideration for rehabilitation and closure (see ARPANSA 2005).

At the national level, the *Strategic framework for mine closure* (ANZMEC–MCA 2000) provides broad guidance on mine rehabilitation, as do the other handbooks in the leading practice series.

Key examples of international guidance on monitoring and its purpose are *Good practice guidance for mining and biodiversity* (ICMM 2006b), *Planning for integrated mine closure: toolkit* (ICMM 2008), *Community development toolkit* (ICMM 2006a) and *Responsible mining: case studies in managing social and environmental risks in the developed world* (Jarvie-Eggart 2015).

3.4 The role of stakeholders

Effective and timely engagement with stakeholders is a critical aspect of leading practice rehabilitation management. In this context, stakeholders are all those with a justifiable interest in or concern about the project and its impacts (positive or negative) on the post-mining land use. They are not a homogeneous group. In some situations, the number and variety of stakeholders that the operation might need to consult on rehabilitation appear daunting. Their geographical proximity to the operation is not necessarily a good indicator of their importance, so the first step in engagement is to map potentially relevant stakeholders.

Stakeholders' engagement on rehabilitation objectives is a critical aspect of objective-setting. It is very important to align their expectations with the realities of rehabilitation as best as possible. Many recent examples of mining projects incurring costs and delays in rehabilitation and relinquishment can be traced to poor stakeholder engagement as a result of the company's risk management.

The level of influence that external stakeholders can have on the rehabilitation outcome should be clearly outlined. For example, regulatory requirements might preclude some novel post-mining land uses (such as a golf course or a dirt-bike track). Make such restrictions clear to stakeholders from the outset. There have been many cases in which stakeholders who have outlined unachievable preferences have become disengaged.

Engagement with stakeholders can take many forms and serve a number of purposes. People and organisations can be engaged:

- as sources of baseline data and resources for monitoring rehabilitation:
  - land holders
  - Indigenous communities
  - universities and other researchers
  - state environment departments
  - environmental NGOs
- as groups potentially affected by the operation's impacts on the environment and post-mining rehabilitation objectives:
  - Indigenous communities
  - other local communities
  - regulators (federal, state and local government)
  - people and organisations at all levels with an interest in the region's biodiversity
- as land management partners:
  - Indigenous communities
  - NGOs.

4.0 REHABILITATION PLANNING

Key messages

- Assess the rehabilitation and environmental baseline as early as possible in project development.
- Characterise topsoils and overburdens from the exploration phase and continue through the pre-feasibility and feasibility stages as a basis for mine planning.
- Perform a comprehensive soil survey before or at the start of operations.
- Design the final site landforms as early in the project as possible to minimise costs.

4.1 Rehabilitation and environmental baseline

An adequate and accurate baseline assessment of the local environment is an important starting point for a leading practice mine-site rehabilitation program, so it is important to begin assessing the rehabilitation and environmental baseline as early as possible in project development.

Baseline environmental and social surveys are usually conducted as part of planning and environmental impact assessment for mining projects. Where possible, baseline and monitoring data that informs rehabilitation planning and implementation should be built into environmental and social impact assessment surveys.

Critical baseline data should include:

- for climate, long-term average daily rainfall, rainfall intensity, temperatures and evaporation
- for soils, pH, salinity, exchangeable cations, soil depths, plant available water-holding capacity (PAWC), soil nutrients, organic carbon profiles, annual water balances and erodibility
- for vegetation and ecosystems, species, functional groups, canopy and contact cover, and rooting depths
- fauna presence and populations.

Special consideration should be given to rare or endangered plant or animal species, which may be critical for rehabilitation targets.

A robust assessment of the rehabilitation baseline improves the project design team's understanding of how far rehabilitation can realistically address and mitigate the impacts of the operation, and can also inform the development of guidelines or procedures for materials handling and placement to ensure that rehabilitation targets can be achieved.

It is also good practice to begin rehabilitation trials as soon as possible. Where rehabilitation is the most significant critical control for dealing with impacts, there should be high certainty of success, from either similar rehabilitation exercises elsewhere or trials run as part of the project. At the same time, short-term goals can be set to track the development of critical vegetation services, such as surface cover, soil structure and water entry.

The Environment Protection and Biodiversity Conservation Act (EPBC Act) offset guidance requires project proponents to estimate the confidence of success for their rehabilitation, and requires that estimate to be justified by the results of onsite trials and offsite successes in similar biotic environments and habitats and using similar rehabilitation techniques.

Early baseline data collection and rehabilitation planning are also important to ensure that the right steps are taken during construction and operations to enable rehabilitation later on. This might include topographic and hydrological surveys of the site; documentation of the site vegetation; the collection and storage of topsoil; the strategic placement of wastes; and the collection of germplasm (seeds, cuttings, seedlings) if another local source is unavailable.[2]

Baseline data collection methodologies should be matched with the primary land use of the pre-disturbance environment and with the rehabilitation objectives. For example, a site that disturbs improved grazing land and has that land use as its rehabilitation objectives should include rangeland quality assessment methodologies in its rehabilitation baseline.

4.2 Materials characterisation

The properties of materials excavated and placed into waste landforms are critical and can dramatically affect rehabilitation costs and success. The characterisation of topsoils and overburdens should commence in the exploration phase and continue through the pre-feasibility and feasibility stages as a basis for mine planning. Such information may even determine whether excavations are open cut or underground. Early characterisation of materials can enable planning to avoid significant risk and to make the best possible use of materials that may be desirable for site infrastructure and rehabilitation.

Broadly, the characterisation of wastes will initially aim to identify high-risk materials that will require special handling or selective placement. Those are materials for which there is significant risk of acid mine drainage, asbestiform fibres, high salinity and movement of salts and/or specific elements in drainage and run-off, and high rates of erosion (tunnel erosion being a particular concern).

The lithology of the wastes to be excavated can inform landform design. For example, the presence of a high proportion of competent hard rock enables higher and steeper waste landforms to be planned than would be the case if all wastes were highly oxidised, fine-textured and highly erodible. Again, selective placement may be needed to take advantage of specific wastes that are more useful for landform stabilisation and rehabilitation.

Initial pit cross-sections have the potential to provide an early instalment of much of this information, but the characterisation of wastes should continue throughout the operation of the mine, particularly where the ore grade and mine plan change.

Soil surveys are typically required as part of mining proposals, and are used to provide information on the available soil resources, on the relationship between soils and vegetation ecosystems, and on the likely topsoil resources that could be harvested for rehabilitation works. Generally, analyses and characterisation focus on the chemical, mineralogical and physical properties of the materials.

The quality of the data obtained is highly dependent on the sampling design or strategy. Costs can be reduced to some degree by strategic bulking of subsamples, but it remains critical to apply an appropriate sampling intensity. Dollhopf (2000), De Gruijter (2002) and Yates & Warrick (2002) provide useful guidance on sampling protocols.

2 This might also require further understanding of seasonal flowering and seeding to ensure that seed can be collected at the right time.

4.2.1 Wastes

Wastes commonly present as a mix of coarse (rock) particles and finer material. The proportion and size of rock particles may vary depending on the methods of excavation, but an initial analysis could be expected to consider:

- rock size distribution and content
- the salinity of coarse and fine particles
- the acid-producing potential of the waste
- specific elements that may cause concern for drainage or run-off quality
- the presence of asbestiform lithologies.

If the waste is considered to have potential for use in rehabilitation works (for example, placed close to the landform surface or mixed with topsoil), then additional analyses (largely on the fine components) could usefully include:

- rock competence
- particle size distribution (including contents of clay and silt)
- pH and chloride content
- sodicity and tunnel erosion risk
- erodibility
- water-holding capacity
- fertility.

4.2.2 Topsoils

Commonly, either desktop or broadscale soil surveys are carried out during initial planning and approval stages for a project. However, a more comprehensive soil survey is generally required at, or by, the commencement of operations. This may take the form of surveys at intervals of one to several years to assess soil resources in planned disturbance areas before topsoil salvage and site excavation.

The required intensity of sampling (both observation sites and analysed profiles) should be clearly defined before the survey. Guidance on soil survey methods is in:

- *Guidelines for surveying soil and land resources* (McKenzie et al. 2008)
- *The Australian Soil Classification* (Isbell 2002)
- *Australian Soil Survey and Land Survey field handbook* (NCST 2009)
- *Soil and landscape issues in environmental impact assessment* (DLWC 2000)
- *Protocols for soil condition and land capability monitoring* (DECCW 2009).

Information collected may include current land use and condition and landscape attributes, together with morphological descriptions of soil profiles. For each identified soil type, a number of profiles should be sampled and analysed by a laboratory accredited by the National Association of Testing Authorities or the Australian Soil and Plant Analysis Council. Different analytical suites can be adopted on the basis of site properties and existing soil information.

A typical analytical suite for reference soils (DECCW 2009) is:

Topsoil and subsoil suite

- chemical tests, including pH, electrical conductivity (EC) (1:5 water), cation exchange capacity and exchangeable cations, organic carbon, total nitrogen, available phosphorus
- physical tests, including particle size analysis, Emerson aggregate test, drained upper limit and crop lower limit.

The presence of rocks, although undesirable for agricultural operations, is often quite useful for mine rehabilitation. Surface rock cover can reduce erosion potential (Simanton et al. 1984) and increase water movement to depth, thereby reducing salinity impacts in some situations (Jennings et al. 1993).

4.3 Landform design

4.3.1 Timing

To minimise the costs of final landform shaping (and possible multiple handling), it is critical to have landform designs prepared as early in the project life as possible.

Therefore, it is equally critical that rehabilitation objectives for final land use, stability and long-term management are discussed and agreed with regulators and key community stakeholders as early in the mine's life as possible. Detailed design of landforms and their construction cannot be done (and significant savings achieved) until those objectives are established. The greater the delay in such planning, the less the savings that can be achieved.

4.3.2 Design strategies

Generally, the aim of mine rehabilitation is to eventually achieve closure, sign-off and relinquishment of the miner's responsibility for the mined area. For some post-mining land uses, such as grazing, continuing site management may be needed, but other uses may require none. For that reason, leading practice design often attempts to avoid long-term reliance on engineered structures as much as possible.

Engineered structures such as graded banks, berms and rock drains are designed for certain conditions, such as a specified rainfall return period, and can be expected to fail eventually when those design conditions are inevitably exceeded. As well, there is (commonly) gradual loss of capacity in berms due to erosion and deposition, and the settlement of waste landforms can significantly alter constructed flow paths, so that continuing maintenance is required.

In many instances, engineered structures are incorporated into landform designs as temporary structures to be removed once vegetation establishment reaches the point that erosion risk and run-off rates are significantly reduced.

4.3.3 Batter profiles and risk

Despite suggestions that reconstructed mined landforms should, wherever possible, mimic natural landforms within the region of the operation, it should be understood that most waste landforms are essentially large mounds of unconsolidated materials that may—in their properties—bear little, if any, relationship to the rock and weathered material making up nearby natural landforms. Nor, unlike on natural slopes, is there potential for any incision that occurs to be constrained by underlying bedrock. Consequently, mimicking natural landforms without any consideration of material properties has a very high probability of failure, particularly where erosion risk is high.

For waste landforms, risks of failure can vary enormously, and that should affect the design processes and effort applied. High-risk landforms have some or all of the following characteristics:

- low vegetation cover (probably associated with low rainfall or with rainfall patterns)
- high rainfall erosivity
- high batter slopes (the definition of 'high' varies with climate and materials, but in many situations ≥60 m would be considered high)
- highly erodible materials
- limited capacity to reduce gradients to effective levels.

Conversely, low-risk sites have some or all of:

- high and effective vegetation cover
- moderate rainfall erosivity (associated with rain of low intensities but sufficient volume to grow vegetation)
- low batter slopes (commonly ≤20 m)
- materials of low erodibility, often with significant content of competent rock
- capacity to reduce gradients to effective levels.

For low-risk sites, a wide range of landform design options can be applied, landform aesthetics can be thoroughly addressed, and the application of dedicated software can deliver effective outcomes.

However, where landform risks are high, there is a considerably greater requirement to develop designs very closely attuned to site materials, climate and revegetation outcomes. Generally, this requires careful material characterisation and the appropriate use of run-off/erosion and landform evolution models.

Current leading practice in Australia has made extensive use of soil erosion and landform evolution models to develop landform profiles that are site and goal specific (Howard et al. 2011) and in many cases incorporate most or all of the elements considered aesthetically desirable. Effective designs are based on:

- site climate and rainfall erosivity
- the erodibility of the materials used to construct the landform
- the likely vegetation cover and resultant changes in soil function.

Examples of model application and reviews of options are in Hancock et al. (2000, 2003); Loch (2010); Howard et al. (2010); and Howard & Lowe (2014). Advanced options delivered by or able to be considered by modelling include:

- concave profiles, which can significantly reduce the erosion of some materials (figures 6 and 7)
- incorporation of rock to reduce erodibility and increase infiltration
- placement of tree mulch to provide surface erosion control at strategic points on the slope
- modification of soil infiltration capacity by vegetation growth (Figure 8).

Figure 6: Successful revegetated and stable concave slope profile (Murrin Murrin Nickel operation north-west WA goldfields region)

Note: Full bond return was achieved 4 years after rehabilitation.
Photo: R Loch.

Figure 7: Concave slope and tree debris at Wattle Dam mine near Kambalda, WA

Photo: R Gerrard.

Figure 8: Successful revegetation at Wattle Dam mine 4 years after revegetation, underpinned by gypsum treatment of underlying waste, fertilisation of topsoil, elimination of berms (to avoid tunnel erosion) and placement of tree debris to control erosion

Note: see Howard et al. (2010).
Photo: R Gerrard.

There has been extensive application of the Water Erosion Prediction Project (WEPP) run-off/erosion model (Flanagan & Livingston 1995) (for example, Loch 2010) and the SIBERIA landform evolution model (Willgoose et al. 1991). Although there has been widespread use of various factors from the revised universal soil loss equation (RUSLE) (Renard et al. 1997), caution is advised in the application of that model, as it gives average erosion rates for a slope only and gives no information on peak erosion rates that may develop at points along a slope. Other models are under development and trial, but potential users of any model should consider:

- whether the model has been validated and the level of accuracy demonstrated
- the availability of accurate and appropriate input data (preferably directly measured)
- the applicability of the model to the situation of interest.

Provided accurate input data is used, models such as WEPP can give considerable certainty that landform stability will be consistent with site requirements and expectations (Howard & Roddy 2012a).

There is currently no broad agreement on what constitutes an ‘acceptable’ rate of erosion on a rehabilitated mine site. Early US erosion model development triggered interest in tolerable erosion rates, with a value of 12.6 t/ha/y being suggested for maintenance of the fertility of cropland (Wischmeier & Smith 1978). For undisturbed soils, both Wight & Siddoway (1979) and Skidmore (1979) noted that a tolerable soil loss rate of 4.5 t/ha/y was set for rangeland, and Skidmore suggested that a value of 2 t/ha/y may be appropriate for some fragile rangeland soils. A common Australian approach has been to adopt a target erosion rate such that rill erosion and eventual gully development are unlikely.

In some instances, proximity to sensitive receiving waters may mean that target erosion rates are defined by water-quality objectives, whereas in others the maintenance of surface soil productivity may constrain short- and long-term target erosion rates.

4.3.4 Placement of landforms

Constructed landforms need to be sited so they do not interfere with important landscape features and potential future ore reserves. Consideration should be given to existing overland flow paths on the site to ensure that the landform does not divert or obstruct any valued streams. Impacts on fauna movement and access to watering points should also be avoided.

4.3.5 Footprint minimisation

The area of land disturbed by landform construction (the footprint) should be minimised where possible. However, a trade-off is needed to avoid having that priority lead to the construction of steep, high landforms with little potential for stability. In addition, steep, high landforms might 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 depends on:

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

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

4.3.6 Managing tunnel erosion potential

A range of Australian mine wastes and soils are highly susceptible to tunnel erosion. When it develops, tunnel erosion can cause serious failures of mine landforms, and particularly of engineered structures placed on them. Tunnel erosion is commonly associated with materials that contain dispersive clays and with materials that contain high proportions of highly mobile fine particles. Methods for identifying and managing tunnel-prone materials are outlined in Vacher et al. (2004) and Landloch (2006).

First, the wastes and soils to be used in rehabilitation should be assessed for clay dispersion and for tunnel erosion risk. Care should be taken not to rely on simple tests of dispersion, as soil salinity can mask the effects of sodicity. (As soluble salt is leached out of materials placed close to the soil surface, a stable saline/sodic material can be converted to non-saline, sodic and unstable.)

Clay dispersion is commonly caused by elevated levels of exchangeable sodium, by low soluble salts or by elevated levels of magnesium (or some combination of all three factors). To prevent or reduce dispersion, amendment with a source of calcium such as gypsum (or lime if the material is acid) could be considered. If using gypsum, note that its dissolution is slow and that it should be added to soil/waste as soon as possible (preferably when topsoil is initially stripped) to give some time for it to dissolve and to replace sodium within the soil or waste. Rates of gypsum are estimated on the basis of soil/waste cation exchange capacity, exchangeable sodium (or magnesium) content, bulk density, and the volume to be treated.

Where tunnel-prone materials are present, care should be taken in designing and constructing the landform to eliminate or minimise any concentration and prolonged ponding of overland flows. Drainage control structures that pond run-off are commonly subject to tunnel erosion.

4.3.7 Water balances and deep drainage

If the landform contains materials of concern (such as potential for acid drainage or the transport of some pollutant, such as high soluble salts or some specific element), the waste dump design needs to consider both the control of deep drainage (which could increase the potential for undesirable seepages) and the minimisation of erosion (which could ultimately expose the encapsulated material).[3]

Nonetheless, if seeking to reduce deep drainage into and through a landform, it is important to consider some basic principles:

- Compacted barrier layers—if close to the active zone of wetting/drying and biological activity—commonly fail in the short to medium term.
- Store-and-release covers can greatly reduce deep drainage, but there will still be some drainage in extremely wet years.
- The effectiveness of store-and-release covers can vary greatly, depending on two critical parameters: the magnitude of the soil water store available for plant use and the effectiveness of vegetation in using the stored soil water.

A range of studies in the Queensland Murray–Darling Basin have demonstrated that—for deep-rooted native trees on clay soils with high plant available water capacity (PAWC) in southern and central Queensland—drainage to depths below 2.4 m can be quite low. This is illustrated in Table 1, which shows selected data from Yee Yet & Silburn (2003) on modelled annual deep drainage for a location near Theodore in central Queensland. For that location, simulations considered:

- PAWC consistent with a range of soil types in southern and central Queensland
- slight changes in PAWC (generally only 5–12 mm) due to differences in rooting depth between vegetation types
- differences in transpiration between vegetation types.

3 Capping layers and the encapsulation of waste are covered in greater detail in the *Preventing acid and metalliferous drainage* leading practice handbook (DIIS 2016a).

Table 1: Modelled annual deep drainage at Brigalow Research Station in central Queensland).

SOIL	RUDOSOL	GREY SODOSOL	TENOSOL	RED DERMOSOL	GREY VERTOSOL	BLACK VERTOSOL
PAWC (mm) to 1.5 m	43	51	88	132	182	232
PREDICTED DRAINAGE (MM/Y), FOR BRIGALOW RESEARCH STATION (702 MM RAIN/Y)						
Woodland	100	59	14	5	0	0
Pasture	142	111	78	19	2	0

Source: adapted from Yee Yet & Silburn (2003).

A range of other research on soil soluble salt profiles in the region (of which Tolmie et al. 2011 is a useful example) has confirmed that these modelled estimates of drainage are consistent with field performance. However, the following comments from Yee Yet & Silburn (2003) on vegetation impacts are instructive:

> Trees potentially reduce drainage for two reasons (a) they have deeper roots than crops or pastures and hence create a greater soil water deficit, and (b) they transpire for more days of the year compared to crops and winter dormant pastures i.e. more 'green days' throughout the year. Little is known about the depth of root water uptake of trees in the [Queensland Murray–Darling Basin] and on some soils it may be no greater than for grasses and crops. However, it is unlikely that grasses and crops will have deeper roots than well-adapted, healthy trees and other perennials. Similarly, it is unlikely that crops, and pastures in most cases, will have more 'green days' than evergreen trees. Therefore trees or perennial vegetation generally have greater evapotranspiration and less drainage than other vegetation types.

The challenge for the rehabilitation of mine landforms is to be able to deliver a store-and-release cover of suitable depth and texture to provide sufficient PAWC and adequate fertility to support the growth of trees and grasses.

Note also that the discharge of water 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 needed 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 of grass—are high, it may be 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 those situations, high levels of surface contact cover are essential.

If water is retained on the top of the waste dump or tailings storage facility, it is essential to consider the potential for prolonged ponding and damage to plants. There is also potential for water ponded on top of a landform to infiltrate and then cause subsidence within loosely dumped materials, creating sinkholes. For these reasons, the depth and duration of ponding at any point on the landform surface should be minimised. Keeping the top of the landform level, maximising surface roughness and installing bunds to create relatively small cells of 1–3 hectares can achieve this.

The establishment of deep-rooted vegetation to increase water use is also recommended.

4.3.8 Managing surface drainage flows

A range of options is regularly adopted for 'managing' surface flows. Because such options may carry significant long-term risk, the decision to construct an engineered flow control or drainage network should be made with some care.

Perimeter bunds may be installed to contain rainfall excess on the top of the landform and infiltrate it relatively evenly in level cells (see, for example, Squires et al. 2012), rather than to have uncontrolled flows discharged onto outer batter slopes and cause gullies. Alternatively, flow paths may be formed on the top of the landform and designed to deliver excess rainfall to some stabilised discharge point. The top of the landform may have one catchment or multiple catchments, each with a designated discharge point. Decisions on how to manage excess rainfall on the top of a rehabilitated landform are influenced by perceived risks from deep drainage, by the prevailing climate and likely run-off rates, and by the soil and vegetation conditions able to be created on the landform top. The larger the flow that is collected into one channel, the greater is the difficulty of stabilising its discharge, and the greater the potential damage if the stabilisation strategy fails.

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 berm failure. Once berms fail, they discharge concentrated flows onto the batter slopes below and initiate gullies. The reasons for berm failure include inaccurate construction, tunnel erosion and overtopping due to deposition of sediment. Where erosion rates remain significant (as is common in arid areas where surface vegetation cover is too low to provide erosion control), outer batter profiles that include berms will need regular maintenance (desilting) as long as the erosion continues, or else they will fill with sediment and overtop, causing gullying (Howard & Roddy 2012b).

Risks and consequences associated with the presence of berms on waste landforms have been widely documented (Loch & Willgoose 2000; Vacher et al. 2004; Loch & Vacher 2006; Stevens 2006; Howard et al. 2010). For this reason, some sites have adopted a practice of using berms or some form of cross-slope bank during initial rehabilitation, then removing the berms once vegetation has established and stabilised the slope. Other sites have adopted options that enabled them to avoid the use of berms; strategies have included the strategic placement of tree debris to control erosion (Howard et al. 2010) and the incorporation of rock into the surface of outer batter slopes to reduce erosion potential. Another option is to use erosion modelling to design concave slope profiles to reduce erosion potential (Howard et al. 2010). This can give significant reductions in erosion potential, although only on suitable materials.

5.0 REHABILITATION IMPLEMENTATION

Key messages

- The construction of rehabilitation landforms varies considerably and is often largely dictated by mining excavation methods.
- A range of software is available to enable companies to optimise the costs of waste dump construction by ensuring optimal haul and dumping schedules.
- The selection of plant species to be used in rehabilitated areas is influenced by rehabilitation objectives, completion criteria and the post-mining land use.
- The growth medium placed in areas to be rehabilitated must be capable of supporting a self-sustaining vegetative cover.
- Major rehabilitation management issues are fire, weeds, feral animals, erosion, plant diseases and nutrient cycling.

In this section, rehabilitation implementation techniques are separated into subsections: landform construction; species selection; establishment of a plant growth medium; physical amelioration; chemical amelioration; biological amelioration; fauna recolonisation; and rehabilitation management.

There is significant overlap between the subsections, which should ultimately be integrated into a detailed rehabilitation prescription.

5.1 Landform construction

The construction of rehabilitation landforms varies considerably, often largely dictated by excavation methods. For example, dragline spoil piles offer little option for selective placement, whereas truck/shovel operations 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 the software uses inbuilt assumptions that affect the results, so those assumptions must be clearly understood to achieve the planned outcome.

Equally, savings in the cost of initial dumping are of little value if the costs of final reshaping are subsequently greatly increased. Dumping should generally be carried out to optimise reshaping to the final landform.

Surface roughness is an important consideration in the rehabilitation of mine-site landforms. Roughness tends to trap water and seed, and it is generally accepted that a rough surface will provide better vegetation establishment than a smooth one. However, while the creation of large surface roughness through 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, as large roughness elements tend to concentrate flows over greater widths of slope and those large flows then cause higher rates of erosion. Although some surface roughness is generally good, it does not naturally follow that large roughness elements are therefore better. The value of surface roughness is closely linked to its persistence through time, which is largely controlled by the particle size distribution (rock content) of the material in which the roughness is created and the degree to which overtopping may or may not develop new flow paths.

5.2 Species selection

The selection of plant species to be used in rehabilitated areas is influenced by rehabilitation objectives, success criteria and the intended land use (Section 3.2). In some instances, particular vegetation forms and species may be needed to achieve specific ecosystem functions, such as critical levels of surface contact cover, nutrient cycling or fixation, and impacts on infiltration and deep drainage.

Different species may be required for different domains on the site. The physical, chemical and biological aspects of the growth medium must also be considered, particularly when there has been significant modification to the medium's condition due to prior land use, to stockpiling or to the influence of mining or processing.

Where there has been significant modification, a useful approach can be to search the local area for natural analogues of the post-mining landscape and mine soils and use them as models for the proposed post-mining ecosystem.

If natural analogues cannot be found, that should not be seen as a limitation. One option is to select species that are tolerant of the conditions within the growth medium and an appropriate mix of life forms to meet the rehabilitation objectives. Alternatively, the growth medium may need to be amended or managed to ensure that rehabilitation objectives can be met.

Case study 3: Species selection and topsoil management at Alcoa's bauxite mines in Western Australia

At Alcoa's Western Australian bauxite operations, monitoring the species composition of unmined jarrah forest provides the baseline data used to select species for restoring mined areas. Alcoa does pre-mining vegetation surveys on a 120 m x 120 m grid throughout areas to be mined. In addition, a network of permanent 20 m x 20 m forest plots has been established in parts of the jarrah forest where mining typically occurs. These two data sources are used to determine the species richness target for areas that are being restored and to guide species selection for the seed mix that is applied to restored areas and for the plants that are grown in Alcoa's nursery. Alcoa has established an internal target of achieving 100% plant species richness in restored areas. In practice, this means that a 20 m x 20 m monitoring plot in restored forest should have the same number of species as a 20 m x 20 m plot in unmined forest. However, establishing a restored jarrah forest with a composition that is similar to that of unmined forest is also important.

About 60% of the species on restored sites originate from seeds in fresh topsoil that is stripped from 'donor' sites that have been cleared in advance of mining and is immediately 'returned' to areas that are being restored. Using fresh topsoil from donor sites is important because fresh topsoil results in at least 33% more species in restored sites than topsoil that has been stockpiled before use.

Previously, fresh topsoil was returned using scrapers. However, it is challenging to apply thin layers of topsoil evenly using scrapers. To enable more efficient use of the limited fresh topsoil, a recent development has been to spread thin (10–25 mm) layers of soil using a modified articulated truck.

Fresh topsoil being spread in a thin layer on a newly restored mine pit.

Species-rich understorey in unmined jarrah forest, with abundant monocot species (especially rushes and sedges).

The botanical monitoring data from unmined forest is used to identify species that are abundant in the forest, but that are either absent from or occur only in very low numbers in restored areas. Those species are targeted for inclusion either in the broadcast seed mix or for nursery propagation. If seed is available in large quantities, broadcast seeding is the preferred option. However, the jarrah forest also contains a significant number of long-lived, slow-growing resprouter species, particularly rushes and sedges. Those species are highly abundant in unmined forest but do not re-establish from the fresh topsoil used in restoration and often produce few seeds or seed that is difficult to germinate, making them unsuitable for inclusion in a broadcast seed mix. These so-called 'recalcitrant' species are propagated in Alcoa's Marrinup nursery and then planted into newly restored areas. Research over more than 20 years has resulted in the development of suitable propagation techniques for a range of recalcitrant species. Tissue culture is used for the rushes and sedges and cuttings for most of the broad-leaved understorey species. Each year, Alcoa produces and plants around 450,000 recalcitrant plants into newly restored areas.

Tetraria capillaris (Cyperaceae) produced by tissue culture and planted in a restored site. The plant is surrounded by a plastic mesh guard to discourage grazing by kangaroos.

The initial revegetation effort must establish the building blocks for a self-sustaining system, so that successional processes lead to the desired vegetation complex. Vegetation studies from environmental impact assessments should be used as a starting point for a species list if the objective is to return mined areas to a vegetation type similar to the one that existed before mining. Non-native species should generally be avoided but may be considered when the intended post-mining land use is grazing or cropping, or when they are widely endemic in surrounding areas.

For native ecosystems, a combination of ground cover, shrub and tree species should be used. Rarer or threatened species should also be considered if the growth medium is suitable for their establishment. This could occur using direct transplants that were rescued before clearing or using seed that was harvested from cleared plants or plants from adjacent areas.

A cover crop can be sown with the native species to protect the replaced soil against erosion in the first year, before the slow-growing native species can give some protection. In such cases, sufficient fertiliser should be added to achieve the desired growth of the cover crop without adversely affecting the native species. For example, a cover crop of oats is sown with fertiliser and native seed over mulched areas in heavy mineral sands mining rehabilitation near Eneabba in Western Australia. The oats provide protection for germinating seedlings in the first season and are then replaced by fast-growing pioneer species in subsequent seasons (Petersen & Brooks 1996).

However, in some cases, the cover crop may compete with the target vegetation for scarce plant nutrients and soil water. As well, although appearing to provide high levels of contact cover, cover crops often do not achieve the stem density and levels of surface contact cover needed to control erosion by surface flows. Consequently, revegetation strategies should be considered in the light of site-specific conditions.

5.3 Establishment of a plant growth medium

The growth medium placed in areas to be rehabilitated must be capable of supporting a self-sustaining vegetative cover. It should:

- have adequate infiltration capacity
- have an adequate available water capacity
- have adequate aeration
- provide an adequate rooting depth, not restricted by mechanical impedance or by hostile subsoil conditions
- be capable of supplying adequate plant nutrients
- be free from excessive salinity, acidity and alkalinity
- provide the microbial associations necessary for plant growth.

It may be possible to create suitable growth medium from the excavated overburden or tailings alone, or from topsoil placed on those materials. To achieve a satisfactory root zone, soil and overburden may have to be handled selectively. This involves placing materials that are not suitable for plant growth deep within the profile and placing suitable material near the surface. If there is a deficit of topsoil (as is often the case with older mines), inert subsoil material may be suitable but is likely to require additional physical, chemical and, in particular, biological amelioration before it will be suitable for plant growth.[4]

4 The following subsections set out amelioration options. The subsections on physical, chemical and biological amelioration are particularly relevant where overburden or tailings material is used as the growth medium.

Topsoil is often the most important factor in successful rehabilitation, particularly where the objective is to restore a native ecosystem. A decision on whether soil should be conserved during mining can be made only after a thorough evaluation of the nature and distribution of the soil and overburden types before mining. In general, soil should be conserved and used in the rehabilitation program when overburden material or tailings cannot support the desired post-mining land use, even if ameliorative treatments costing up to the cost involved in conserving and replacing the topsoil are applied.

However, in exceptional cases, the topsoil may contain excessive weed seed loads or introduced grasses that may out-compete the target vegetation. If the cost of managing the weeds in the topsoil after it is spread exceeds the cost of ameliorating the subsoil to make it a suitable growth medium, then the topsoil should be buried. If introduced and invasive grass seed loads in the topsoil are an issue, one alternative is to place strips of topsoil with intermittent strips of overburden material. Native tree and shrub species are seeded directly into the overburden. The topsoil areas provide immediate grass coverage and act as a source of grass seeds to invade the overburden areas once the native trees have established, thereby overcoming the problem of the introduced grass species outcompeting the native trees and shrubs. This strategy is highly dependent on the rehabilitation objective, material properties and intended land use.

Most surface soils have fewer limitations to plant growth than overburden material, and the additional cost of soil handling is generally outweighed by greater success in the establishment of vegetative cover. The advantages and disadvantages of conserving topsoil for rehabilitation are outlined below and should be assessed for the particular site.

The use of the entire soil profile is usually only advisable if all horizons are satisfactory for plant growth or are able to be made satisfactory through chemical amelioration. The horizons may be removed and subsequently placed in order, or they may be mixed. However, mixing subsoil is not recommended if it has attributes such as elevated salinity, sodicity or P-fixation capacity that would result in considerable reduction of the value of the topsoil as a growth medium.

Stripping the surface horizon separately from the subsoil provides the opportunity to re-create, as nearly as possible, the original soil profile, with the nutrient and microbial rich A horizon at the surface where it will be maximally exploited by plants' roots. Double-stripping the topsoil, in which the top 50–100 mm of soil is removed and returned separately and on top of the remaining topsoil, may be warranted, particularly where the aim is to restore the native flora. Most of the seeds are stored in this top layer of soil, and its removal and return as a thin layer on the surface maximise the contribution of those seeds to the post-mining flora. Some of the advantages and disadvantages of using topsoil in a rehabilitation program are listed in Table 2.

Table 2: Advantages and disadvantages of using topsoil in a rehabilitation program

ADVANTAGES	DISADVANTAGES
Seed supply	Weed infestation
Beneficial microbes	Cost
Reduces fertiliser	Erosion hazard
Cover is established more rapidly	Competition
Burial of rock	
Reduces adverse properties of overburden	

If the soil seed bank is important for rehabilitation success, then during rehabilitation operations the topsoil should be handled in a manner that will conserve plant diversity in the topsoil seed bank and maximise plant establishment after respreading. Specific considerations for managing the soil seed bank 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 before mining, if that 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. The final topsoil surface should be freshly placed and suitable for direct seeding, if that is to follow.

Ideally topsoil, should not be stockpiled but should be lifted, transported and spread on a recontoured area in one operation (known as 'direct return'). When topsoil is double-stripped, the top horizon should be directly returned where possible and the lower horizon can be stockpiled adjacent to the area where it will be used in the rehabilitation. Direct return has several advantages compared with placing the topsoil in stockpiles and storing it for later rehabilitation. First, it avoids double handling. Second, the need to create stockpiles may mean that extra land must be cleared. Third, and most importantly, stockpiling reduces the quality of the soil resource. Stockpiles become anaerobic, soil structure deteriorates, organic matter and nutrients may be lost, seeds deteriorate, other plant propagules die and populations of beneficial soil micro-organisms are reduced significantly. For example, investigation of the seed in the topsoil before mining and throughout the rehabilitation procedure following bauxite mining in Western Australia showed that much of this valuable store was being lost during the rehabilitation process. However, it also demonstrated that fewer seeds were lost when topsoil was directly returned (50%) to rehabilitation sites rather than being stockpiled (15%) (Koch et al. 1996).

In contrast, Keipert (2005) concluded that most topsoil deterioration occurred in the first 12 months of stockpiling, regardless of the height of the stockpile. In the Hunter Valley, where space for topsoil stockpiles is limited, Keipert found it acceptable to stockpile material in large dumps and focus on ameliorating the physical, chemical and biological aspects in the rehabilitation process. This emphasises the importance of matching the identified rehabilitation land use to the site limitations in different mining regions around Australia.

However, weather conditions and the difficulties in timing rehabilitation to suit mining activity usually mean that at least some soil must be stockpiled for later use. Stockpiling for longer than about six months may cause structural degradation and the death of seeds and micro-organisms. If the topsoil must be stockpiled, it should be for as short a time as possible and the stockpiles should be:

- as low as possible (<2 m), with a large surface area
- revegetated to protect the soil from erosion, discourage weeds and maintain active populations of beneficial soil microbes
- located where they will not be disturbed by future mining, as excessive handling will adversely affect soil structure.

Topsoil and subsoil material should be stockpiled separately. Topsoil should not be handled when it is wet because that may lead to structural deterioration that is difficult and costly to ameliorate. Ideally, soils should be stripped and replaced at a moisture content of between 10% and 15% to avoid the adverse effects of compaction and structural breakdown. The site should use GIS to maintain an inventory of topsoil stockpile volumes and locations to ensure the most efficient use and management of the material. Mapping of soils during environmental impact assessments should be used in stripping areas to ensure that the maximum amount of topsoil is used.

Topsoil can be stripped and returned using a variety of machinery, the most common techniques being a loader and truck, scraper or bulldozer pushing topsoil into a windrow.

5.4 Physical amelioration

Rehabilitated areas should be ripped to remove compaction from heavy machinery, encourage infiltration of water (except in cases where there is a particular reason to discourage infiltration, as noted above) and prevent erosion. If engineered waterways are included in the landform, areas should be ripped on a grade (such as 0.5%). Otherwise, they should be ripped on the contour. Ripping is generally done by a bulldozer, although shallow scarifying can be done with tractors or graders. Ripping depths vary depending on the type of spoil material, the depth of topsoil and the equipment used for rehabilitation operations. For example, ripping at some sites may aim to bring rock up to mix with topsoil and reduce its erodibility. In other cases, care may need to be taken to avoid mixing underlying sodic or saline wastes into topsoil.

Mixing rock into surface soil can be useful for reducing erosion potential (Howard & Lowe 2014), and for increasing infiltration and leaching of salts to depth (Jennings et al. 1993). However, it is important to achieve the correct rock:soil mix (Howard & Lowe 2014), and the stability of the fine component mixed with rock remains important. Where the fine component is dispersive, flows typically continue to erode it irrespective of rock cover (Figure 9).

Figure 9: Progressive erosion of a drain formed on dispersive sandy soil with limited rock cover—(left) initial erosion and (right) increasing incision

Photos: R Loch.

5.5 Chemical amelioration

Common concerns with the chemical properties of overburdens and topsoils include extremes of pH, sodicity, salinity and low fertility.

5.5.1 pH

In dealing with native plant communities, note that the pH range commonly specified for agricultural crops might not be relevant for rehabilitation works. Native vegetation may be adapted to pH extremes, and information on baseline soil conditions is essential. Where necessary, lime or sulphur could be used to modify pH.

5.5.2 Sodicity

Soils are described as 'sodic' when exchangeable sodium exceeds 6% of cation exchange capacity, and 'highly sodic' when it exceeds 15%. Sodic soils are commonly prone to clay dispersion, although there are interactions with soil salinity, with other exchangeable cations, and with clay type and content. Consequently, experienced soil scientists should be involved in the assessment of dispersion risk.

Dispersive overburden and topsoil are prone to surface crusting, low permeability and hard setting, as well as being (generally) highly erodible and susceptible to tunnel erosion. The impacts of clay dispersion are more significant in materials with greater than 10% clay. The degree of dispersion is also affected by salinity: elevated levels act as a suppressant.

The application of gypsum should be considered for these materials. Specific soil tests should be done to determine application rates, but generally 5–15 t/ha is required. Gypsum application to reshaped rehabilitation areas can be difficult due to their relatively high gradients, and aerial application has been used in some cases. For topsoils, gypsum application before initial stripping is strongly recommended, as gypsum is mixed into the soil by the stripping process and then has a longer period in which to dissolve and interact with the soil. Note that gypsum is not highly soluble, and its significant effects on soil properties may be slow.

5.5.3 Salinity

Saline wastes are common in mining. Generally, there is little that can be done to remediate them. Management strategies are to identify them and to ensure that they are not placed close to the surface of rehabilitated waste landforms.

Care may be needed to minimise or manage saline seepage from the base of waste dumps containing saline materials. Options include the minimisation of deep drainage (which could leach salt from the landform), the use of salt-tolerant vegetation, mixing with rocky waste to increase salt leaching from the plant root zone, and encapsulation if possible. Equally, the movement of saline seepage to depth and to local groundwater may need to be addressed.

5.5.4 Fertility

In many situations, the prepared growth medium will involve some depth of topsoil placed over waste of varying degrees of suitability for plant growth. The resulting 'soil' is likely to contain totals of plant nutrients that are greatly different from (and lower than) those found in the target ecosystem that the rehabilitation works seek to establish. Consequently, fertilisation can be necessary to replenish those levels that can be critical for ecosystem sustainability, but there are challenges. In a functioning ecosystem, a proportion of the nutrient totals are present in the above- and below-ground biomass, and a very high proportion is in slowly available form as organic matter (Westman 1978). The application of a single large quantity of some nutrient in highly soluble form as fertiliser may not achieve the desired outcomes. Weed growth may be encouraged, nutrient may be lost or immobilised, and the necessary nutrient pools and cycling may not be achieved. Therefore, thought needs to be given to:

- the nutrient levels needed to initiate plant growth
- what nutrients will be subsequently added to the system by plant activity
- a strategy to achieve the final ecosystem, complete with functioning pools of nutrient in various forms and quantities and with appropriate cycling.

An initial application of fertiliser is often required in rehabilitation areas, particularly to replenish nitrogen levels that are lowered through oxidation during topsoil handling and to encourage the growth of grasses to control erosion hazards.

Soil samples should be collected and analysed to determine the appropriate fertiliser type, formulations and application rates. Typical application rates of nitrogen- and phosphorus-rich fertilisers are 100–300 kg/ha. However, site-specific trials should be run to determine the most appropriate rate. Ripping, fertilising and seeding are often carried out in the one operation to avoid compaction and disturbance from using several different vehicles for those operations or from making several passes with the same vehicle.

Ongoing application of fertilisers is not common but may be necessary in some cases as the ecosystem develops, to ensure that nutrient totals are achieved. (Soil phosphorus is often a major limitation.)

Where native shrubs and trees are being established on mined land, nitrogen-fixing legume species are normally included in the seed mix; those species can fix up to 20 kg N/ha annually. Organic fertilisers (such as biosolids, mulch and compost) are generally beneficial but often costly and difficult to apply. Unlike most inorganic fertilisers, they are beneficial both as fertilisers and as soil amendments. Excessive application of fertiliser (particularly nitrogen) can exacerbate an existing weed problem and should be avoided.

When metal toxicities occur, there are two strategies for obtaining a plant cover: reducing the toxicity or using metal-tolerant plant species. The solubility of many metals can be reduced by liming to raise the pH, by adding phosphorus fertiliser or by incorporating organic matter, such as sewage sludge, to complex the metals. There is a limit to what can be achieved in this manner, however, and the aim in a rehabilitation program should be to avoid having potentially toxic materials in the root zone. The application of agricultural lime at a rate of 2.5–3.5 t/ha will increase pH by approximately 0.5 units, provided soil pH is not greater than 5.0.

5.6 Biological amelioration

The most significant form of biological amelioration in rehabilitated mining areas is the establishment of vegetation. The vegetation must be matched to the rehabilitation objective and intended land use (see Section 4.2.2). Plant species can be established on rehabilitated areas from propagules (seeds, lignotubers, corms, bulbs, rhizomes and roots) stored in the topsoil and by:

- sowing seed
- spreading harvested plants with bradysporous seed (seed retained on the plant in persistent woody capsules) onto areas being rehabilitated
- planting nursery-raised seedlings
- transplanting individual plants from natural areas
- transferring substantial amounts (> 1 m^2) of relatively undisturbed soil with its vegetation intact from natural areas
- allowing invasion from surrounding areas through vectors such as birds, animals and wind.

Each of these techniques is discussed in more detail below. Generally, a combination of techniques is needed, and cost is the most significant driver for the selection of the most appropriate techniques.

Usually, the seed reserves in replaced soil must be supplemented with additional seed collected from vegetation on or near the mine site. Sowing seed is an economical and reliable method for establishing some species. Seeding results in a more random distribution of plants than planting seedlings, and leads to more natural-looking vegetation. Other advantages of direct seeding include low labour costs and no check on growth rates through planting out, meaning that a more heterogenous spread of plant sizes within a species is likely. Risks include a higher risk of failure through adverse climate conditions, competition from weeds, loss of seed to insects and low seed germination rates.

A number of aspects need to be taken into account to increase the chances of success with direct seeding:

- **Seed supply:** Seed may be collected or purchased, but quality control over all stages of the process is critical regardless. Planning for native seed collection should commence at least one or two years before the seed is 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 assemblies. After collection, seed needs 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 distribution, 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 which 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, successional aspects of the ecosystem must be considered. Pioneer species that readily colonise disturbed areas should be included in the seed mix; however, species characteristic of later successional stages should also be established early if experience proves that 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. The high seeding rates of some early colonising species may reduce overall diversity by out-competing other species.

- **Seeding rate:** Seeding rates should be determined by trials at the mine site. Common rates for native tree and shrub species used in the bauxite and heavy mineral sands mining industries are 1–3 kg/ha, of which 25–35% of the total weight is seeds of canopy species such as eucalypts. The ultimate survival rate in direct sowing is typically 1–5% for fine-seed species and 5–10% for coarse-seed species. Assuming 75% seed viability, a rough guide to sowing rates is 0.1–1.0 kg/ha for fine-seed species and 2–4 kg/ha for coarse-seed species. The application rate for each species in the seed mix should be based on the desired density in rehabilitated areas, adjusted for seed viability, germinability and establishment rates. In areas of open woodland or where grass swards are both an important component of vegetation assemblages and essential for surface stabilisation, grass seeding rates of 10–20 kg/ha may be needed.
- **Seed spreading:** The methods for spreading seed partly depend on what labour and equipment are available. They can include spreading by hand, helicopter, fixed-wing aircraft, 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:** Timing of seeding can be important for successful revegetation. In most cases, seed should be sown immediately before the expected onset of reliable rains or after the break of the season. Native seeds may require specific moisture and temperature conditions to germinate, so that they establish at the optimal time of the year for survival. This need for multiple cues may allow seed to be sown well before it would normally be expected to germinate.
- **Spreading vegetation:** In some plant communities, such as heathlands, many plant species do not readily release their seeds. Such 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 usually more economical to establish plants by direct seeding than by planting seedlings. Planting nursery-raised seedlings is most appropriate when the particular species cannot be established in suitable numbers through seeding or topsoil return, or where the target plant density is not high. It may be possible to propagate such species from seed, cuttings, divisions or tissue culture, grow them on in containers in a nursery and then plant them as part of the rehabilitation process. Planting out seedlings on a regular basis requires a reliable supplier of consistent quality seedlings or an onsite nursery. The advantages of planting seedlings include more efficient use of available seed, potential for appropriate mycorrhizal infection of seedlings, control over species mix and placement, and no limitation on the species included in the revegetation program. Disadvantages include higher costs for planting and nursery operation or purchases of seedlings, a check in growth rate at planting, the need to pre-order or sow several months before expected use, the longer planting time required and the possible deterioration of seedlings if planting is delayed.

When planting seedlings in rehabilitated areas, consideration should be given to:

- the time of year (normally, just as the most reliable rainfall for the year begins to fall)
- whether to use planting tools or machines
- maximising the availability of water to the seedlings (for example, by planting them in the bottom of rip-lines into which scarce rainwater will flow)
- whether to provide water to the plants by physically watering them or by establishing a trickle reticulation system
- 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 protection from grazing animals (such as biodegradable guards)
- providing the correct amount and type of fertiliser.

Direct transplanting of species that cannot be established by other means is possible by transferring slices or front-end loader buckets of soil with the vegetation intact (known as 'habitat transfer'). However, this is an expensive option.

Some species, although not easily established using other techniques, will invade from surrounding forest areas over time. For example, many orchid species are not found in young bauxite mining rehabilitation but invade over time as the required mycorrhiza develop in the soil and litter ecosystems (Grant & Koch 2006). Invasion from surrounding areas can be increased by maximising the surface area of boundaries between the rehabilitation area and the surrounding forest, and by leaving forest islands in the middle of rehabilitated pits.

Some plants fail to re-establish on rehabilitated sites where the aim is to restore the native flora, despite the application of seed and the use of fresh topsoil. These are often species that typically respond to disturbance by resprouting from epicormic buds under the bark or from various underground storage organs (such as lignotubers, corms, bulbs, rhizomes and roots). Such recalcitrant species should be the focus of further research to learn more about their life cycles and explore alternative mechanisms for establishing them in rehabilitated areas.

Plants form beneficial symbiotic associations with a number of soil micro-organisms, including fungi, bacteria and actinomycetes (single-celled plants usually found in the soil). Mycorrhizas are a natural component of the ecosystem in most Australian soils. They are very important in Australia, as they are necessary to ensure the establishment of some plant species. Most native plant species used in rehabilitation probably form associations with vesicular arbuscular mycorrhiza (VAM) and ectomycorrhizal fungi. These fungi have been shown to be effective in increasing the uptake of phosphorus by plants growing in deficient soils. The ability of VAM fungi to associate with plants is rapidly depleted by topsoil disturbance and stockpiling. This often results in low levels of infection in the early years of rehabilitation. Similarly, only a limited number of ectomycorrhizal fungi species have been observed in young rehabilitations. As a result, some species may not colonise rehabilitation areas until specific mycorrhiza have recolonised. To conserve mycorrhizal inoculum, topsoils should be directly returned wherever possible; when stockpiling is unavoidable, the piles should be low and revegetated as soon as possible. More recently, biological inoculums have been developed and applied in rehabilitated areas to accelerate the reintroduction of critical microbes.

5.7 Fauna recolonisation

Animals will usually colonise rehabilitated areas if the composition and structure of the rehabilitated vegetation are similar to surrounding areas. Experience has shown that some key components of fauna species' habitat requirements might not be present in rehabilitation areas for many decades. Methods for reintroducing missing habitat components include:

- transplanting grasstrees
- conserving and re-using vegetation by chipping or respreading it as mulch or branches to provide shelter for small invertebrates and reptiles, erosion protection and nutrients
- constructing nest boxes to provide shelter and breeding habitat for many bird and mammal species
- returning cleared timber to establish shelter in the form of logs and log piles for ground-dwelling species to shelter in or under
- constructing reptile habitat by a limited distribution of surface boulders
- constructing perches used by raptors and other birds (which may introduce seeds)
- establishing old dead trees ('stags'), which provide hollows, crevices and exfoliating bark, all of which provide shelter for many smaller reptile and invertebrate species.

Not all of these techniques will be suitable in all situations, and a cautious approach should be taken because some may introduce more problems than they solve. Furthermore, they must be aligned with the identified rehabilitation objective and intended land use (for example, rock or log piles might not be compatible with that land use).

Case study 4: Protecting habitat for threatened black cockatoos in the jarrah forest of Western Australia

Alcoa manages the effects of bauxite mining on threatened fauna in the jarrah forest of Western Australia through a threatened species management program. The forest red-tailed black cockatoo is one such species. It nests in large hollows of jarrah forest trees, particularly very large (more than 1.5 m diameter) and old (more than 200 years) marri trees.

Conserving trees with hollows is an important strategy in managing the effects of mining, and is achieved in a number of ways. No mining occurs in designated old-growth forest stands, which preserve veteran jarrah and marri trees. Buffer zones around old-growth stands, in which mining is excluded, are also established. Within the broader production landscape, Alcoa has developed procedures for identifying and managing nest habitat.

The aim of this strategy is to conserve sufficient natural nest habitat to help maintain breeding populations. This involves:

- pre-mining surveys to identify and map nest trees in areas planned for haul roads and mine pits
- using GIS mapping to inform and assist mine planning to prioritise and protect nest habitat
- monitoring the breeding use of tree hollows through all stages of mining.

For example, nest-tree mapping information is used when designing haul roads, drainage sumps and soil stockpile areas to avoid clearing nest trees where feasible. Nest trees in potential operational areas are individually assessed and prioritised for protection based on their historical use by cockatoos, their condition and their proximity to other nests outside the area to be cleared.

In addition, about 100 ha of forest that is significant for the conservation of black cockatoos has been identified and excluded from mining at Alcoa's Myara operations. The area has a high concentration of nest hollows (more than 40) and is also an important roosting site for several hundred cockatoos.

Management strategies for all the threatened species in the area are supported by a fauna research program that seeks to better understand their ecology and habitat requirements.

A female red-tailed black cockatoo sitting at the entrance of a nest hollow. The tree is estimated to be 250 years old. Nests are monitored for breeding and recruitment using a novel pole camera system, which was used to take this photo.

Photo: T Kirkby.

A cockatoo chick can be seen in the bottom centre of the image.

Photo: T Kirkby.

5.8 Rehabilitation management

The objective of rehabilitation management is for the rehabilitated area to be self-sustaining and resilient and to require no more management effort than surrounding undisturbed areas. The major rehabilitation management issues are fire, weeds, feral animals, erosion, plant diseases and nutrient cycling. Success criteria require that these issues have been addressed before lease relinquishment can be considered. The major management issues for rehabilitated areas are discussed in more detail in this section. This topic is also covered in the *Mine closure* leading practice handbook (DIIS 2016b).

Fire is a major factor in the development of plant communities in Australia. Some species are intolerant of fire or are intolerant when they are young. A fire protection plan may be needed to protect the rehabilitated area for a number of years until the plants are able to survive fire or have set seed, so that they can become re-established after fire. Fire control strategies can include firebreaks, hazard reduction burns in adjacent areas, prescribed cool burns in rehabilitated areas and weed control. Grant et al. (2007) summarised fire ecology work conducted on rehabilitated bauxite mine sites in the jarrah forest of Western Australia. It involved the use of fire to assist in the successional development of rehabilitated areas as well as demonstrating resilience to fire as a disturbance agent. That work was instrumental in demonstrating the sustainability and resilience of the rehabilitated areas and facilitated the issuing of a completion certificate for large areas that were previously part of the Jarrahdale mine.

Controlling the introduction and spread of weeds is an important consideration in rehabilitation. Weed infestations on rehabilitated areas can be very difficult to control, so the emphasis should be on prevention rather than cure. Weeds in areas adjacent to the disturbed area should be controlled to reduce the potential seed load. Care must be taken that weeds are not introduced to the area in manures or as contaminants in seed of desirable species. There are many examples of plant species that have become weeds after being knowingly or unwittingly introduced into Australia, and this possibility should always be considered when introducing exotic species in a rehabilitation program. Techniques for controlling weed species include physical/mechanical, chemical, biological and ecological methods. A vigorous cover of the desired plant species is often an effective impediment to invasion by weed species. Cultivation, hand weeding, burning and herbicide spraying can all be used in attempts to control weed infestations. However, control can be difficult where there are plants that need to be retained growing among the weeds. Selective grass herbicides can be used for grass weeds in areas revegetated with non-grass species. Hand weeding is expensive but can be effective for smaller areas.

Feral animals can severely damage rehabilitated areas through further disturbance. These introduced species can be controlled on mine sites and in adjacent areas through the use of baits that are non-toxic to native animals (such as 1080) and fencing (in some cases). Firearms are generally not allowed on mine sites, which eliminates shooting as a potential control.

Maintaining or increasing the ability of the soil to supply nutrients, to store and supply water and to support root growth should be a major concern in developing a sustainable ecosystem. The re-establishment of nutrient cycles is essential to the sustainability of rehabilitation. Mining removes the vegetation and inevitably leads to the loss of some plant nutrients from the site. This is particularly important where the proportion of the total nutrients in the ecosystem that is contained in the vegetation and the plant litter on the soil surface is high, as is the case in many Australian ecosystems. In such cases, there must be an input of nutrients to the system if it is to reach a productivity level equivalent to the pre-mining ecosystem and be self-sustaining in the long term. This can sometimes be achieved through a single application of fertiliser during the establishment phase of the rehabilitation. However, sometimes follow-up applications are needed, particularly for grazing or cropping land uses. Regardless, it is important that nutrient cycles be monitored in the rehabilitated area and that the results support the re-establishment of a functional ecosystem.

Any development of significant erosion should be monitored. Generally, incision by overland flows (rills, gullies or tunnels) can be a concern because of its potential to gradually increase over time. When considering the need for and the type of remediation action, both the cause of the erosion and its potential to increase need to be assessed. In some cases, the remedial action may cause more disturbance or damage to the rehabilitated area than the specific issue that is being addressed.

6.0 MONITORING PERFORMANCE

Key messages

- Leading practice rehabilitation monitoring should have clear objectives, be well designed and be clearly integrated into whole-of-life mine planning to ensure that timely and cost-effective solutions are developed to facilitate sustainable mine closure.
- Rehabilitation performance indicators and completion criteria should be assessed against realistic site-specific rehabilitation goals, accounting for the physical resources and scale of disturbance.
- The indicators or parameters to be monitored need to be carefully selected and resourced to enable useful long-term monitoring and evaluation of the response to rehabilitation.
- Monitoring should inform adaptive rehabilitation management.
- Planning for closure should start before mining, and rehabilitation and its monitoring should be progressive through the life of the mine.

6.1 Monitoring

Monitoring and evaluation are essential to better understand and guide rehabilitation practices. Without the progressive evaluation of rehabilitation efforts, there is the risk of reducing the credibility of the science and practice of mine rehabilitation and the liability that the company might not rehabilitate adequately to enable lease relinquishment.[5]

Monitoring is the gathering, analysis and interpretation of information for the assessment of the progress and completion of rehabilitation. Monitoring commonly used in the rehabilitation context includes monitoring of water content and quality; soil surface stability and erosion; the hydrology of waste rock dumps and tailings ponds; air quality and gas emissions; the development of vegetation; colonisation by fauna; and the extent to which rehabilitation and final land-use objectives are being met.

Management informed by monitoring and auditing helps the mining company achieve acceptable and sustainable development outcomes by ensuring that processes and procedures are implemented to track social and environmental parameters. The tracking of progress should determine whether agreed objectives or performance measures have been addressed and should demonstrate that success criteria have been met to show that the site is safe for humans and wildlife, non-polluting, stable and sustainable (for example, the site is able to sustain an agreed post-mining land use) (ANZMEC–MCA 2000; DEHP 2014).

It is unlikely that those conditions can be demonstrated in less than five years following the end of mining in a particular section of a mine site (ANZMEC–MCA 2000). Therefore, it is particularly important that

5 Further details for monitoring performance are in other leading practice handbooks in this series, including E*valuating performance: monitoring and auditing* (DIIS 2016c), *Mine closure* (DIIS 2016b) and *Biodiversity management* (DIIS 2016d).

support mechanisms (such as accounting and onsite staff) and maintenance resources (such as machinery needed for reshaping erosion gullies) are available. These conditions are best met when the mine is still operational, so it follows that progressive rehabilitation should be adopted; where the opportunity exists, rehabilitated areas can be relinquished progressively.

6.2 Development of a monitoring program

Leading practice rehabilitation monitoring has several main components based on knowledge of mine sites in Australia and the ICMM*'s Good practice guidance for mining and biodiversity* (ICMM 2006b):

- Technical process
  - Documentation of rehabilitation procedures, including ground preparation; the use of topsoil (sources, handling, storage length); fertiliser types, application rates and history; seed mix (composition, rates and application); the density of species planted; and the occurrence of disturbances such as fires—all critical for interpreting monitoring results at a later date.
- Biotic variables
  - Other routine information often collected at mine sites, such as information about rainfall, temperature, relative humidity, wind speed, site run-off, groundwater level and quality, vadose (above-watertable) zone processes, sedimentation, water infiltration, and water levels in watercourses, is also very useful in understanding why a particular rehabilitation result was achieved.
- Reference sites
  - Baseline and continuing monitoring of unmined reference or analogue sites (often illustrating pre-mining conditions) provides for useful comparisons in benchmarking or quality control.
- Biological/successional processes
  - Initial establishment monitoring, which is undertaken soon (<2 years) after rehabilitation operations have concluded, is a useful quality control step.
  - Long-term monitoring beginning 2–3 years after initial establishment evaluates the progress of the rehabilitation towards long-term trajectories and whether or not those trends are likely to deliver a sustainable ecosystem in the long term.

Good record-keeping by those doing the monitoring is critical in enabling managers to observe how the history of the rehabilitated landform relates to the performance of current rehabilitation practice. That evaluation is essential in completing the feedback loop so that continuous improvement can be achieved and is vital where mine staff might not remain at the site for the duration of the rehabilitation.

6.2.1 What makes a good monitoring program

Effective monitoring requires a commitment to make systematic and reliable measurements that are sufficient, comprehensive and precise enough to detect changes in conditions due to rehabilitation efforts, as distinct from those due to natural environmental variation, followed by appropriate management actions if necessary (Barker 2001). This can only be achieved if the monitoring program is carefully conceived and rigorously designed.[6]

6 As was emphasised in a survey of mine-site environmental managers in Western Australia on the adequacy of mine rehabilitation monitoring practices (Thompson & Thompson 2004).

An effective rehabilitation monitoring program takes the following key steps:

- Identify clear, unambiguous monitoring and rehabilitation objectives.
- Identify suitable reference sites to allow at least broad comparisons with rehabilitated areas.
- Select sampling units and methods appropriate to the system (for example, with appropriate stratification of soil types or vegetation).
- Establish adequate spatial and temporal coverage to address the objectives.
- Use enough replication to enable statistical analyses of results at an acceptable power with predetermined effects.
- Avoid or minimise bias when selecting the monitoring locations (for example, by randomising replicate selection in the sampling design).
- Use pilot testing to evaluate the effectiveness of the sampling design for the site conditions.
- Use training and testing to ensure that the methods are repeatable and comparable over time and between different observers.
- Maintain quality control to ensure that the data enables statistical analysis and inference (Green 1979; Legg & Nagy 2006; Lindenmayer & Likens 2010).

6.3 The role of reference or analogue sites

Mining often causes immense changes to the hydrology (surface water and groundwater), topography and geology of an area (Doley et al. 2012). In addition, variability in topsoil handling, seeding operations, the level of early establishment management and other site conditions make it difficult to predict how a rehabilitation will progress, particularly in the early years. Therefore, reference sites should be used for early guidance and not as firm targets (Nichols 2004).

Once the ecosystem successional trajectory is more predictable (demonstrated by a slowing of structural development trends, stabilising species richness and progress towards the identified success criteria), it is appropriate to review or refine the reference targets. Using the state-and-transition model approach in Grant (2006) helps to understand the development trajectory.

While comparative standards have some limitations, there remains value in establishing benchmarks in unmined systems for several reasons. For example, benchmarks:

- provide a guide on the level and type of vegetation cover and its influence on infiltration and run-off water
- allow evaluations of climatic and seasonal influences that may affect the rehabilitation's progress
- provide insights into water availability and movement across reconstructed landforms and how they might affect nutrient availability in the rehabilitated system.

Box 1

Neldner and Ngugi (2014) demonstrated the potential of aggregating three local eucalypt woodland communities at the Meandu mine in south-east Queensland to form a benchmark. They used the BioCondition assessment framework (Eyre et al. 2011) as a 'scorecard' to assess the current condition of a rehabilitated site against the benchmark. This way, an established vegetation condition assessment was adapted for use in a mine rehabilitation setting and adapted to local conditions to provide site-appropriate rather than aspirational evaluations of rehabilitation for sites less than 50 years old.

An important complement to this was the modelling system (Ecosystem Dynamics Simulator) developed to predict the long-term growth of trees and shrubs (Ngugi et al. 2015). This enabled future growth trajectories of trees and shrubs to be measured against the relevant benchmark attributes, providing a framework to support early management interventions and assess risks associated with lease relinquishment.

Box 2

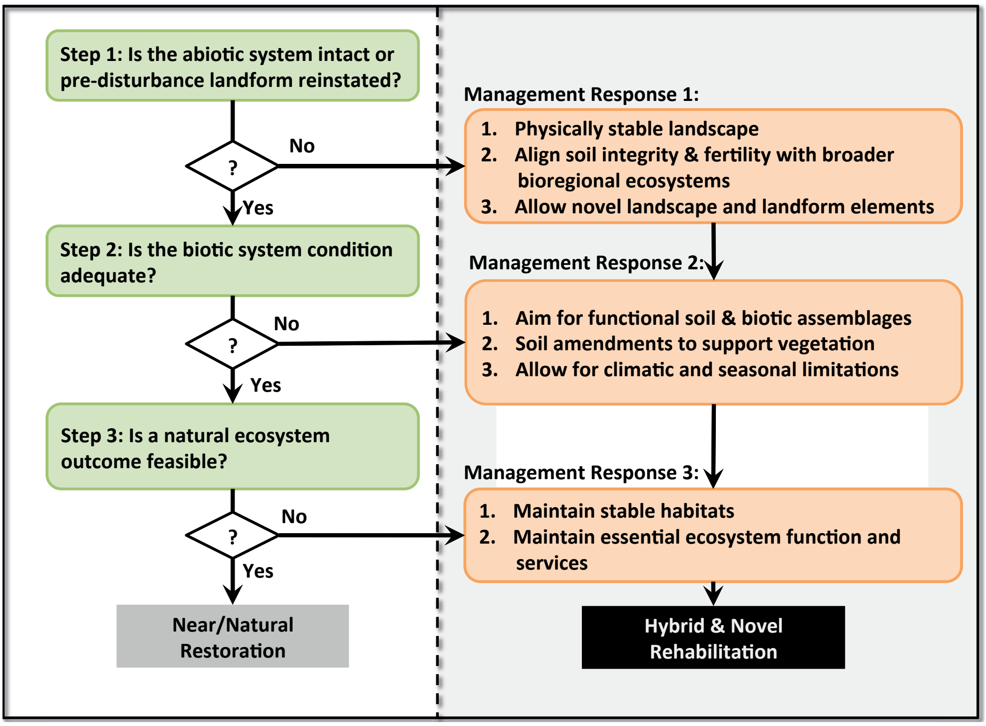
Doley and Audet (2013) proposed a decision-tree (see figure below) to identify the conditions for restoration or rehabilitation (and hence benchmarking) based on the scale of disturbance combined with the limitations of local climate, geology and landforms on plant growth and ecosystem development.

The first step requires a detailed initial assessment of the ecosystem function in addition to an intensive surveillance of risk (Doley et al. 2012). Then, an analysis of landscape suitability and biological function uses the decision-tree to pose a series of questions to help guide proponents to what might be considered achievable within the constraints of the site.

Whether the aim of the rehabilitation is a natural, hybrid or novel ecosystem, the emphasis is on achieving the highest possible standards of ecosystem stewardship and definitely not a compromise on the commitment to or resourcing of rehabilitation.

Using the management responses in the restoration/rehabilitation decision-tree, the guidelines have been applied at a site near Mount Isa and four mine sites in the Bowen Basin (CMLR unpublished data).

Simplified restoration/rehabilitation decision-tree



Source: modified from Doley & Audet (2013, 2014).

6.4 Performance indicators

The testing of rehabilitation outcomes against specific targets or success criteria is usually required for monitoring and reporting on mine rehabilitation projects. The criteria are used to demonstrate the progress and ultimately the success of a biophysical management process.

The number of possible monitoring indicators is very large, but every selection should be appropriate to the location and relevant to the defined rehabilitation goals. Each indicator should be justified by its relevance to the guidelines, industry leading practices, project approval requirements, ecological theory and other sources of similar information. Generally, the selected indicators should be those that are known or expected to be most limiting for successful landform stability, vegetation establishment, development and sustainability.

Typically, there are three strategies for using indicators to evaluate the progress of rehabilitation towards completion (SER 2004):

- *Direct comparison* can be directly measured from reference or analogue site data (such as species richness).
- *Attribute analysis* compares data from the predetermined performance indicators that equate to the rehabilitation goals and closure criteria.
- *Trajectory analysis* examines trends in ecosystem structure and function that progressively develop towards agreed rehabilitation goals.

The last two strategies are probably the more widely used until the vegetation structure and function develop to a state where the system starts to resemble the intended end goal (such as grazing or a near-natural, hybrid or novel ecosystem).

Most rehabilitation projects require success criteria that address abiotic factors, such as landform stability, and the restoration or establishment of ecosystem function and services. Typically, rehabilitation monitoring includes:

- *abiotic indicators:* surface and slope stability; performance of constructed covers (such as mineral wastes); visual amenity; pollution in rehabilitated areas (such as acid mine drainage); properties of soil and root zone media (for example, chemistry, fertility, soil organic carbon); hydrological considerations
- *biotic indicators:* plant community structure (cover, tree and shrub density and height); vegetation composition (species richness, presence of weeds); presence of pest animals; recolonisation by invertebrate fauna (such as ants) and vertebrate fauna (such as amphibians, reptiles, mammals, birds).

Once abiotic and vegetation criteria are considered satisfactory, it is often assumed that fauna colonisation will follow; however, flora criteria have been found to be poor proxies for fauna recolonisation (Cristescu et al. 2013) and direct monitoring may be necessary.

Larger or more complex projects requiring the demonstration of ecosystem functionality may extend to monitoring of ecological processes using indicators such as mycorrhizae colonisation, nutrient cycling (such as decomposition, mineralisation or soil organic matter transformation), interactions between plants and animals and recolonisation of invertebrates. Ecological processes are not measured nearly as frequently as measures of diversity or vegetation structure, as they may be slower to recover and require as frequently as measures of diversity or vegetation structure, as they may be slower to recover and require multiple measurements, increasing the time and cost of the project (Ruiz-Jaen & Aide 2005). Depending on the final post-mining land use, particularly for near-natural restoration, it will become critical to demonstrate a positive trajectory towards a long-term, resilient, functioning ecosystem by measuring a number of ecological processes.

6.5 Adaptive management and quality control

Adaptive management is an iterative process of decision-making in the face of uncertainty with the aim of reducing uncertainties using a risk-based approach. Trigger levels (upper and lower) are used to clearly identify levels at which management responses to unexpected or poor rehabilitation condition are needed. Management tools such as trigger action response plans (TARPs) can help to provide early warning signals that a trend towards unacceptable levels of risk is likely. TARPs are further outlined in *ESG3: Mining Operations Plan* (MOP) *guidelines* (DTIRIS 2013).

6.6 Monitoring techniques

A vast array of monitoring methodologies and tools is available to mine-site environmental personnel and their contractors. Practitioners need to determine how monitoring will inform the progress of rehabilitation, what are the most cost-effective techniques suited to their specific site conditions and where inadequacies in monitoring techniques exist. Without compelling evidence using quantitative data, it is difficult for regulators to approve mine closure and lease relinquishment (Fletcher & Erskine 2013).

Monitoring techniques and technologies are largely dealt with in the *Evaluating performance: monitoring and auditing* leading practice handbook (DIIS 2016c). However, it is important to address some of the monitoring methods for rehabilitation here due to their specific nature and use in analysis.

Some of the attributes most commonly measured in rehabilitation projects throughout the world are plant species diversity, vegetation cover or density, and arthropod species diversity, according to a study of 68 rehabilitation projects (Ruiz-Jaen & Aide 2005). Techniques used to collect data on those attributes typically consist of field sampling units or measurements such as plots, transects and points to determine species counts, densities and cover estimates.

Landscape function analysis (LFA) has been widely used in mining to measure ecosystem function (stability, infiltration and nutrient cycling) and for trajectory analysis by undertaking rapid assessments of soil surface features (Tongway et al. 2003; Tongway & Hindley 2004). The scientific debate over approaches such as LFA compared to more easily measured species and structure based indicators has not been resolved (WA EPA 2006; Erskine et al. 2013). Regardless of the debate, any approach that does not consider the range of abiotic and biotic factors needed to demonstrate safe, stable and functioning land use consistent with the rehabilitation goals is likely to prove unreliable.

6.6.1 Remote sensing

Monitoring using remote sensing techniques is increasingly playing a role in the assessment of mine-site rehabilitation. Previously, the lack of resolution and high cost limited the use of aerial survey techniques for accurately monitoring developing rehabilitation. The advent of high-quality airborne sensors and georeferenced image-processing software has led to a burgeoning array of applications and new technologies. Some leading practice and 'proof-of-concept' examples using remote sensing are provided in the following subsections.

Case study 5: Wesfarmers Curragh coalmine rehabilitation monitoring program

Wesfarmers Curragh coalmine in central Queensland's Bowen Basin has a continuous, ongoing and robust rehabilitation monitoring program, established in 2002. The overall aim of the program is to obtain accurate information about the performance and development of the rehabilitated landforms over time, and in the process build a case for lease relinquishment.

Since the late 1980s, Curragh has been proactively creating an architecture of applied research, examining the most efficient way to establish native tree, shrub and grass species in a number of challenging media options, including bare spoil, stockpiled and freshly stripped topsoil (placed on spoil at various depths), coarse coal reject, and alternating topsoil and spoil strips. One key outcome of past research was that the topsoil–spoil strip method improves tree and shrub germination and supports an increase in native species richness by reducing the competitive impacts of buffel grass (*Cenchrus ciliaris*) (Mulligan & Bell 1991; Orr & Bell 1990).

Traditionally, the rehabilitation monitoring program at Curragh has involved a ground survey using 8 m x 50 m (400 m^2) transects to sample small areas of rehabilitation, under the broad assumption that the random location of transects provides floristic and landform data that is representative of the entire restored landform. However, since 2012 the program has expanded to include the use of an unmanned aerial vehicle (UAV) to provide high spatial and temporal resolution imagery to complement the ground assessment.

The addition of UAV imagery has enabled the collection of valuable information on completion criteria metrics such as erosion hotspots, site slope stability, projective foliage cover and tree and shrub density. In addition, the UAV has shown the potential for site thematic maps and revealed the presence and distribution of weed species such as leucaena (*Leucaena leucocephala*). The UAV is a cheap, reliable way of detecting change-over-time metrics and is particularly valuable for active erosion gullies, bare areas and weed movements across sites. Ongoing monitoring provides regulators, industry and other stakeholders with the confidence needed when demonstrating the development of rehabilitation outcomes and the trajectory towards completion criteria.

Unmanned aerial vehicle assessment

The compactness and useability of UAV technology means that data capture can be tailored for highly specific purposes at resolutions under 10 cm and over a greater range of temporal and spatial resolutions. UAV technology is used at Curragh on an annual basis to provide:

- high spatial resolution (8–10 cm) images of target areas
- data on the presence/absence of erosion areas, including soil loss/deposition volume calculations
- data on the presence/absence of targeted weed species such as leucaena
- 4-band geometrically corrected orthophotos (red, green, blue and near infra-red) of rehabilitated areas
- thematic maps showing the percentage cover of trees, shrubs, bare ground and grass cover and erosion hotspots
- digital surface models showing rehabilitation slope and aspect.

Traditional plot-based assessment

A modified transect-based approach continues at Curragh in order to provide continuity with previous monitoring and to complement remotely sensed imagery interpretation.

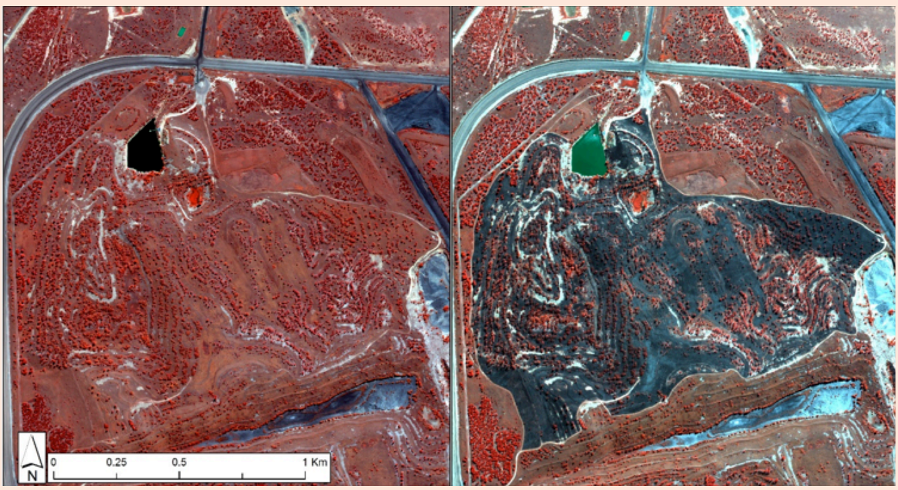
At each new site, three transects of 50 m x 8 m (400 m^2) running downslope and perpendicular to topsoil–spoil strips are established and permanently marked for future reassessments. Metrics measured include:

- the number and heights of woody tree and shrub species
- species richness for the 50 m x 8 m plots
- foliage projective cover
- cover and species presence quadrats
- soil sampling (0–10 cm) of topsoil and spoil media for analysis of EC, pH and macro nutrients.

The results of past and ongoing monitoring provide valuable feedback to site staff, including recommendations on improvements to the rehabilitation process. Increased confidence in the capabilities of UAV imagery analysis is helping Curragh move towards a new monitoring model that will probably involve a reduced ground survey program while maintaining a scientifically robust and accurate understanding of rehabilitation processes and ecological trajectories.

Fire research

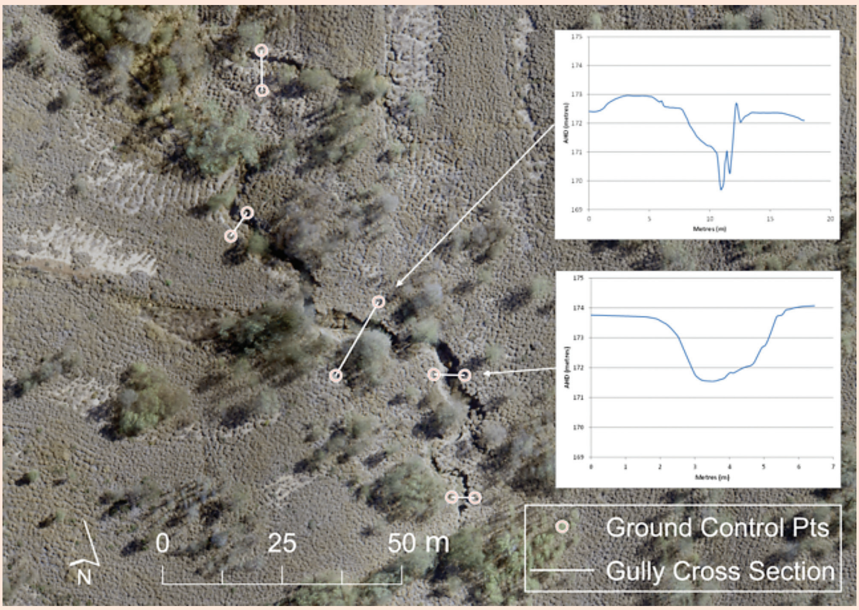
The Curragh mine is testing the resilience of its rehabilitation through a research project aimed at studying the response of buffel grass dominated communities to wildfire. In May 2015, Curragh burned over 100 ha of 21-year-old rehabilitation in one controlled fire. Scientists from the University of Queensland's Centre for Mined Land Rehabilitation are using a combination of remote sensing techniques and ground assessments to study fire behaviour in novel ecosystems and the rehabilitation recovery after fire. The project aims to understand the residual risks that disturbances such as fire present to mine managers and future post-relinquishment landholders.



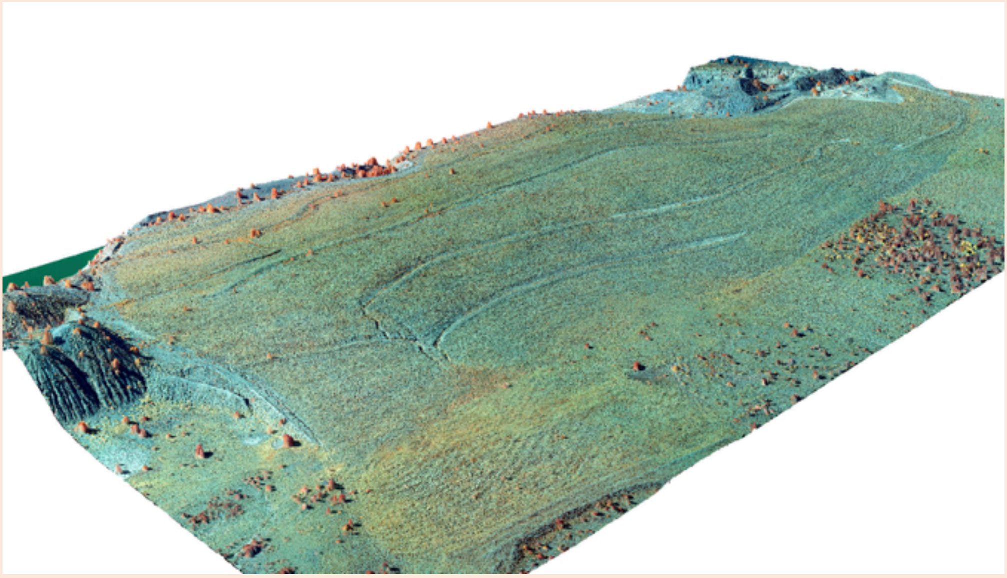
World View-3 multispectral satellite imagery of the experimental fire before (left) and after (right) the burn. Near infra-red shows healthy vegetation as bright red.

Control burn in buffel grass dominated novel ecosystem, May 2015. The resilience of rehabilitation requires testing before lease relinquishment.

Photo Phill McKenna



10 cm UAV orthomosaic showing the presence of an active erosion gully identified through the remote sensing program. This gully is now being monitored over time using UAV orthophoto mosaics, 3D point clouds and field transects to detect long-term change. Graphs on the right show cross-sectional profiles of an active gully, generated using digital surface model measurements at five locations along the length of the gully.



UAV-generated imagery as a base for 3D false-colour point cloud showing trees, erosion gullies and other features.

Aerial photography

Most open-cut mine sites are now using some form of remote sensing, such as aerial photography (~50 cm pixel resolution), on a regular basis. This allows practitioners to prepare some very informative spatial products, such as photogrammetically-derived digital surface models and thematic maps (for example, using iso-cluster analysis in GIS software to demonstrate the presence of bare areas) (DIIS 2016d).

Satellites

Access is now available to much higher spatial and spectral resolution data through the WorldView-2 satellite launched in 2009 and Worldview-3 (WV3) launched in 2015. Worldview-3 has eight multispectral bands (~1.2 m pixel resolution), panchromatic imagery (~0.31 m resolution) and shortwave infra-red imagery (3.7 m resolution).

These new datasets have enabled new methods of monitoring to be developed, such as mapping vegetation health at the Ulan coalmine (NSW) using the Normalised Difference Vegetation Index (NDVI) as an indicator (Raval et al. 2013) to identify subtle changes in vegetation composition and health over time.

In another example, images derived from the SPOT satellites were used to detect and investigate change in the percentage of vegetation cover at the closed Kidston goldmine in north Queensland (Bao et al. 2012). This study used the NDVI and a soil-adjusted vegetation index to examine seasonal influences, such as rainfall, to assess patterns in vegetation condition over time.

Airborne and terrestrial laser scanning (LiDAR)

Airborne light detection and ranging (LiDAR) is often used in mining engineering and surveying to produce a 3D point cloud. Airborne LiDAR has an advantage in that it collects multiple data points from vegetation and ground surfaces. Terrestrial LiDAR or terrestrial laser scanning presents an opportunity to obtain quantitative, highly accurate (<10 mm accuracy) structural characteristics of landforms and vegetation (such as plant height, cover and biomass).

LiDAR technologies are currently underutilised for measuring and monitoring rehabilitation, but there is great potential for their future use. The application of ground-based LiDAR to rehabilitation and closure monitoring and planning and some recent examples are examined in Pratt & Mangan (2013).

Unmanned aerial vehicles

The increasing availability of UAV-derived imagery is providing the mining industry with new approaches to vegetation monitoring. A model that complements the traditional use of plot-based assessments by capturing entire rehabilitation domains while field assessment is being conducted provides a direct link for reference. It allows the extrapolation of point measures to polygon scales without relying on statistical assumptions or increasing the time required in the field.

UAVs using GPS-guided autopilots allow the capture of very high resolution imagery (~5–10 cm pixel resolution) of rehabilitation domains. Applying this technology concurrently with field monitoring provides a direct link between field measurements where plot markers are visible in the imagery and increases the capacity of field staff to assess condition and biodiversity at the polygon scale.

6.6.2 Fauna monitoring

Vertebrate and invertebrate fauna play an important role in the development of a functioning ecosystem after mining, but monitoring of various fauna groups is often less common than monitoring of vegetation. One of the reasons for this is the misconception that fauna will return unaided after the establishment of vegetation (Cristescu et al. 2013; Thompson & Thompson 2004). This is known as the ‘flora equals fauna paradigm’. There is little empirical evidence that restoring flora directly equates to restoring fauna (Critescu et al. 2012).

Incorporating fauna-friendly features in rehabilitated landscapes (for example, improving vegetation structure and composition by using fresh topsoil, controlling feral predators and adding logs and nest boxes) is a step towards addressing this issue. In the case of underground mines, the installation of bat-friendly gates can allow free passage of cave-dwelling bats while restricting unauthorised human access.

Further consideration of fauna monitoring and emerging technologies is in the *Biodiversity management* (DIIS 2016d) and *Evaluating performance: monitoring and auditing* (DIIS 2015c) leading practice handbooks.

Case study 6: Cave-dwelling bats and mines

At least 34 species of bats in Australia use caves and abandoned mines, and 20 of them are classed as rare or threatened at state or federal level. Therefore, using underground mine workings as artificial bat roosting habitat following closure can provide a positive conservation outcome. This has been effectively achieved at various rehabilitated and abandoned mines in Australia and overseas. Mines suitable for use as bat habitats have the following characteristics:

- They are free of toxic wastes and gases.
- They are in hard, stable rock (entrances can be stabilised by cement or metal culverts, which also provide a solid framework for gating if required).
- Roofs can be constructed rock or rough wood with pockets, so that the bats can grip while roosting. Cement roofs may need roughening or need holes drilled in them.
- Lower walls should be relatively smooth to prevent predation by rats and snakes.
- Surfaces should be free of dust.
- The best workings have both overhead cavities and other sections lower than the entrance. This traps warm and cool air in different areas, accommodating varying preferences between species or within species at different stages of the life cycle.
- Internal temperature and humidity need to be more stable than outside conditions, so that the bats conserve energy, particularly during breeding and overwintering.
- Roosting bats need darkness, so the space should be large or complex enough to prevent light reaching roosting areas.
- A replenishing airflow should come from multiple entrances at different levels or, failing that, through an entrance either higher or lower than the main works to create temperature and pressure gradients so that the mine 'breathes' freely.

However, one of the difficulties with using closed mines for bat habitat is human safety considerations. If the area is remote or rarely accessed by the public, leaving the entrance uncovered is the best option. Where liability concerns prevent that, other options include fencing the outer perimeter or lower portion or installing 'bat gates' (metal grids) at the entrance. The guidance of experts in bats and mine closure will be needed, as the different species have differing requirements.

Subsequent monitoring of the artificial bat habitat is needed to determine whether recolonisation has occurred. In recent years, a multitude of studies have demonstrated that the 'field of dreams' assumption (assuming that simply rebuilding fauna habitat will result in wildlife returning) is not accurate, despite being commonly relied upon in rehabilitation.

Monitoring is particularly important when entrances are gated, due to the difficulties many species have in manoeuvring through holes due to their wing morphology and flying agility. Various monitoring methods (including infra-red cameras, emergence counts or directional echolocation recorders) are often site and species specific, so monitoring should be conducted by experienced bat ecologists.

Bats prefer textured surfaces (such as rock or wood) to grip while roosting.
Photo: E Williams.

The Muntapa tunnel in south-east Queensland, with the lower section fenced off to prevent human access.
Photo: E Williams.

A bat gate in the United States.
Photo: B Thomson.

6.7 Reporting

Reporting of monitoring results to regulators and other stakeholders on an annual or other regular basis may be a part of compliance requirements, depending on the mine's initial approvals.

Determining whom the reports go to and who interprets them is sometimes an iterative process between the regulators, the mining company and sometimes external stakeholders. A proactive approach during stakeholder and community consultation is to identify the lines of reporting and the frequency of the monitoring reports.

Reporting on rehabilitation should be progressive throughout the life of the mine to enable regular feedback, rather than happening as the final sign-off approaches. Periodic reporting builds confidence in the applied approaches and techniques for the company, the regulators and external stakeholders. It may also identify gaps in information, highlight issues requiring remediation and reduce the possibility of failing to meet closure criteria.

6.8 Research and rehabilitation trials

The rehabilitation and restoration sciences are still developing fields, and there are few accounts of longer term (20+ years) ecological research and management of rehabilitated landscapes (Doley & Audet 2013), with the exception of bauxite mining sites in Western Australia and the Northern Territory.

It is important that industry and government continue to foster and encourage universities, other research bodies and rehabilitation practitioners to incorporate further research into active and adaptive leading rehabilitation practices.

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GLOSSARY

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's *Good practice guidance for mining and biodiversity* refers to adaptive management as 'do–monitor–evaluate–revise'.

Analogue
Unmined feature against which a mined feature may be compared.

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 run-off water and erosion.

Bund
An earthen retaining wall.

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.

Ecosystem
A system whose members benefit from each other's participation via symbiotic relationships (positive sum relations). The term originated in 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 the magnitude of surface lowering by erosion at that point. As erosion on hill slopes is highly spatially variable, a large number of pins is 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 the 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
In the post-mining phase, an ecosystem that is stable (not subject to high rates of erosion), is 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 that is too steep or inaccessible for conventional seeding techniques.

Leading practice
Best available current practice promoting sustainable development.

Local provenance
For plants, those whose native area is close to where they are going to be planted (for example, in the same local area).

Macropores
Large void spaces between coarse-grained particles.

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

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

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. 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. Reinstatement of degrees of ecosystem structure and function where restoration is not the aspiration.

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.

Restoration
Re-establishment of ecosystem structure and function to an image of its prior near-natural state or replication to a desired reference ecosystem.

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 disrupting of a seed coat to encourage germination.

Slurry
A finely divided solid that 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 6%) 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.

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.

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

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.

SOCIAL
ECONOMIC
ENVIRONMENTAL

Leading Practice Sustainable Development Program for the Mining Industry