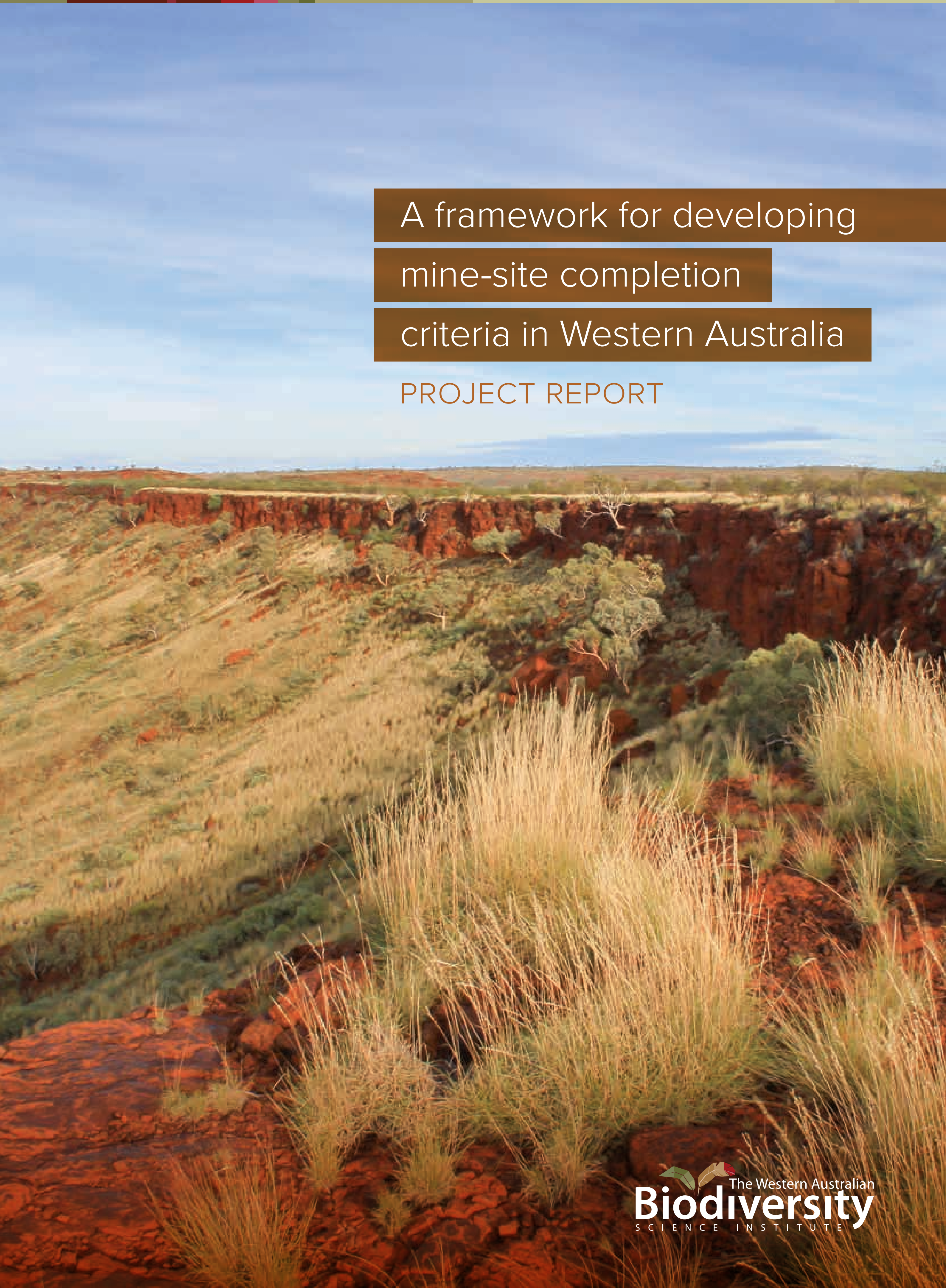

A framework for developing mine-site completion criteria in Western Australia

PROJECT REPORT

The Western Australian Biodiversity Science Institute

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The Western Australian Biodiversity Science Institute

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Photo courtesy: Renee Young

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CONTENTS

CONTENTS (CONTINUED)

CHAPTER 3

CHAPTER 4

CONTENTS (CONTINUED)

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FIGURES

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TABLES

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ACRONYMS

AANDC	Aboriginal Affairs and Northern Development Canada
ABARES	Australian Bureau of Agriculture and Resource Economics and Sciences
AER	Annual Environmental Report
AHP	Analytical hierarchy process
ALUM	Australian Land Use and Management
AMD	Acid Mine Drainage
ANOSIM	Analysis of Similarities
ANOVA	Analysis of Variance
ANZECC	Australia and New Zealand Environment and Conservation Council
ANZMEC	Australia and New Zealand Minerals and Energy Council
APEC	Asia Pacific Economic Cooperation
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
BCA	Benefit-Cost Analysis
BGPA	Botanic Gardens and Parks Authority
BIF	Banded Iron Formation
BoM	Bureau of Meteorology
CMIC	Canada Mining Innovation Council
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DBCA	Department of Biodiversity, Conservation and Attractions
DEC	Department of Environment and Conservation
DEHP	Department of Environment and Heritage Protection (Queensland)
DIIS	Department of Industry, Innovation and Science
DJTSI	Department of Jobs, Tourism, Science and Innovation
DMIRS	Department of Mines, Industry, Regulation and Safety (WA)
DMP	Department of Mines and Petroleum (WA)
DNA	Deoxyribonucleic Acid
DPaW	Department of Parks and Wildlife
DPIRD	Department of Primary Industries and Regional Development
DPLH	Department of Planning, Lands and Heritage
DRF	Declared Rare Flora
DSO	Direct Shipping Ore
DWER	Department of Water and Environmental Regulation
EFA	Ecosystem Function Analysis
EIA	Environmental Impact Assessment
EPA	Environmental Protection Authority (WA)
EPBC Act	Environmental Protection and Biodiversity Conservation Act 1999
ESA	Ecosystem Services Assessment
GNA	Goldsworthy Northern Areas
IBRA	Interim Biogeographic Regionalisation for Australia
ICMM	International Council on Mining and Metals
IGO	Independence Long Pty Ltd
INAP	International Network for Acid Prevention
ISO	International Standardisation Organisation

LCA	Land Capability Assessment
LFA	Land Function Analysis
LGA	Local Gvernment Authority
LiDAR	Light Detection and Ranging
LoM	Life of Mine
LPSDP	Leading Practice Sustainable Development Program
LSA	Land Suitability Assessment
MADM	Multi-Attribute Decision-Making
MCA	Minerals Council of Australia
MCP	Mine Closure Plan
METS	Mining, Equipment, Technology and Services
MGI	Mount Gibson Iron Limited
MLSA	Mined Land Suitability Analysis
MMPLG	Mining Management Program Liaison Group
MOP	Mining Operations Plan
NDVI	Normalised Difference Vegetation Index
NGO	Non-government Organisation
NMDS	Non-metric multidimensional scaling
NRM	Natural Resource Management
NSW	New South Wales
OTU	Operational Taxonomic Unit
OSA	Overburden Storage Area
PAF	Potentially Acid Forming
PCA	Principal Component Analysis
PCQ	Point-Centred Quarter technique
PMLU	Post-mining Land Use
R&D	Research and Development
RCP	Rehabilitation and Closure Plan
ROM	Run-of-mine
RSC	Research Steering Committee
SER	Society for Ecological Restoration
SERA	Society for Ecological Restoration Australasia
SIMPER	Similarity Percentages
SMART	Specific Measurable Achievable Relevant Time-bound
SWOT	Strengths, Weaknesses, Opportunities and Threats
TIRE	Department of Trade & Investment Resources & Energy (NSW)
TOPSIS	Technique for Order Preference by Similarity to Ideal Situation
TSF	Tailings Storage Facility
TSS	Total Soluble Salts
UAV	Unmanned Aerial Vehicle
UWA	University of Western Australia
WA	Western Australia
WABSI	Western Australian Biodiversity Science Institute
WAIO	Western Australian Iron Ore
WRL	Waste Rock Landform

Executive summary

Photo courtesy: Mike Young

The development of acceptable and achievable completion criteria is a necessary part of mine closure planning and fundamental to the successful transition of mined land to a future use. Completion criteria have been defined in the mining context as **agreed standards or levels of performance that indicate the success of rehabilitation and enable an operator to determine when its liability for an area will cease**. Once achieved, they demonstrate to the mining company, regulators and other stakeholders that financial assurances and liabilities can be removed. Because of this important function it is imperative that completion criteria are effectively formulated to capture end-state goals, are accepted by all stakeholders and agreed by regulators and the proponent, are achievable, and can demonstrate this achievement through transparent and appropriate monitoring and documentation.

While considerable progress has been made in mine closure and rehabilitation planning in Western Australia, there remains a need to build capacity and understanding of how to best measure rehabilitation success and to set practical outcomes and measurable completion criteria, particularly with respect to environmental parameters. To address this gap, The Western Australian Biodiversity Science Institute (WABSI) has brought together leading experts, mining industry representatives and regulatory agencies to develop this report.

Scope and purpose

This project was carried out to support the prioritisation of data collection and monitoring activity to enable the development and assessment of completion criteria. Consultation with regulators and representatives from the minerals industry in Western Australia has suggested this is a key gap in enabling more effective mine closure. The report is an independent document developed by the Western Australian Biodiversity Science Institute with two key aims:

- Review the rehabilitation completion criteria and monitoring knowledge base, and
- Develop a science-based framework for post-mining rehabilitation completion criteria and monitoring.

The report has been developed by leading experts in partnership with representatives from key mining industry and regulatory agencies in Western Australia. Its report's development has been strongly informed by the requirements of the resource sector in order to provide information and a decision support framework that best meets the requirements of:

- Mining companies and service providers operating across all geographic regions in Western Australia;
- Regulatory and policy making agencies of government; and
- Public and private research institutions supporting continual improvement.

Being the first project of its kind and to be completed in a relatively short timeframe, the scope of the project gave priority to guidance in the development of biological completion criteria. Addressing the broader range of completion criteria to a high level of detail was not possible with the time and resources available. The report should be read in conjunction with other relevant materials released by the Department of Mines, Industry, Regulation and Safety (WA) and the Department of Water and Environmental Regulation. The process of relinquishment and challenges faced by industry in this space are also not addressed in this document. At the time of publication there were additional projects and documents in development that aim to address some of these knowledge gaps. Updated versions of the report may be warranted in future years to incorporate additional detail towards the non-biological aspects of the framework and the relinquishment process.

Photo courtesy: Mike Young

Report structure

This report has two parts. The first part (Chapter 2) presents a new framework to help guide the decision-making process associated with completion criteria development. The second part (Chapters 3, 4 and 5) document current understanding and perspectives on completion criteria development.

The framework is presented as a process consisting of six steps that enables the industry to demonstrate ability to support the agreed post-mining land use. Each step includes key considerations and guidance to inform the decision making and prioritisation process. The decision-making process should be captured when using the framework to develop site-specific criteria. Tools have been provided to support the recording and presentation of information to demonstrate the process used and application to a specific site. This common set of definitions, processes and methods will also help to reduce inconsistencies across regulators, mining companies and consultants.

The six steps are:

1. Selecting post-mining land uses;
2. Determining aspects and closure objectives;
3. Selecting references;
4. Selecting attributes and risk-based prioritisation;
5. Developing completion criteria; and
6. Monitoring.

The remainder of the report (Chapters 3–5) supports the framework by documenting the current state of knowledge on completion criteria development in Western Australia. It provides the context and directions for users of this guide to consider, and learn from, when developing completion criteria and risk-based monitoring system development.

Chapter 3 consists of a review of existing guidelines, frameworks and principles for the establishment of completion criteria and associated risk assessment that are available in Western Australia, as well as other relevant national or international frameworks. The review presents an assessment of the attributes that may be developed into completion criteria and associated monitoring and evaluation approaches with a focus on the biological attributes as informed by the scope of the project. This provides a valuable reference for informing the development of completion criteria.

Chapter 4 presents the views of stakeholders provided through interviews and surveys within the resources sector. This provides insights into current understanding and consideration of post-mine land use decisions, completion criteria, risk assessment and monitoring practices, and the process of mine closure planning in Western Australia. The interviews and surveys also highlight the key challenges regulators, mining companies and consulting sector face in the identification and evaluation of completion criteria.

Chapter 5 details three case studies of key challenges and decision-making processes at three sites that represent varied environment, mining and social contexts: Goldsworthy Northern Area (iron ore, BHP Billiton), Tallering Peak (iron ore, Mount Gibson Iron) and Northern Jarrah Forest (bauxite, Alcoa of Australia).

1 Introduction

1.1 Completion criteria

Mining is a temporary land use and whole-of-life planning for resource projects that enables the delivery of mutually beneficial post-mining land uses is important to the future progress of the sector (Commonwealth of Australia 2018). The development of acceptable and achievable completion criteria is a necessary part of mine closure planning and fundamental to the successful transition of mined land to a future use. Completion criteria have been defined in the mining context as **agreed standards or levels of performance that indicate the success of rehabilitation and enable an operator to determine when its liability for an area will cease** (LPSDP 2016b).

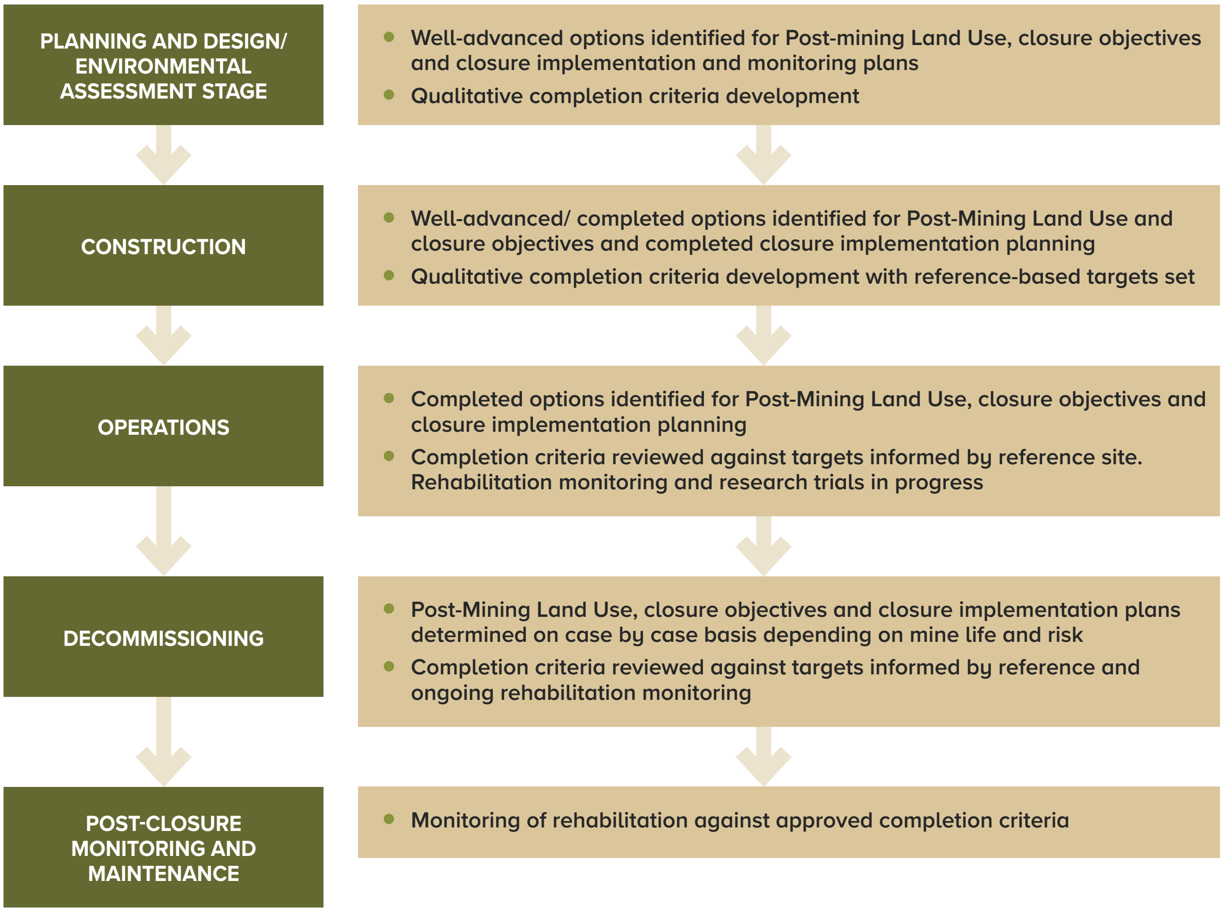
Once achieved, completion criteria demonstrate to the mining company, regulators and other stakeholders that financial assurances and liabilities can be removed. Relinquishment from obligations (where it is legally possible to do so, noting some obligations are not relinquishable – e.g. the Contaminated Sites Act 2003) can ultimately occur if the area is in a state where risks of deleterious environmental, health and safety impacts are at an acceptable level, and the agreed future land use can commence. This is recognised in the Western Australian ***Guidelines for Preparing Mine Closure Plans*** (DMP & EPA 2015) that state:

> *"Relinquishment of a tenement requires formal acceptance from the relevant regulators that all obligations under the Mine Closure Plan associated with the tenement, including achievement of completion criteria, have been met and, where required, arrangements for future management and maintenance of the tenement have been agreed to by the subsequent owners or land managers (e.g. pastoralist, Aboriginal community or land-management agency)."*

While considerable progress has been made in mine closure and rehabilitation planning in Western Australia (WA) (Environment and Communications References Committee 2018), there remains a need to build capacity and understanding of how to best measure rehabilitation success and to set practical outcomes and measurable completion criteria.

Planning for mine closure should occur across the life of mine phases. As a key aspect of the mine closure planning process, the development of completion criteria should be considered from approval stage with activity continuing post closure (Figure 1.1).

Throughout the life of mine there are opportunities for continual refinement to ensure completion criteria are robust and will best demonstrate that closure objectives have been met. Monitoring and the associated use of completion criteria provides a mechanism for adaptive management and refined risk assessments. This is particularly important as continual improvement in rehabilitation techniques will occur over time and proponents should actively include this in their mine closure planning (DMP & EPA, 2015).



Source: Modified from DMP & EPA (2015) Mine Closure Guidelines

FIGURE 1.1 The stages of mining and associated development of completion criteria as defined by the Western Australian mine closure planning process

1.2 Project scope and purpose

The project 'Framework for developing risk-based completion criteria in Western Australia' was carried out to support the prioritisation of data collection and monitoring activity to enable the development and assessment of completion criteria. Consultation with regulators and industry in Western Australia (WA) has suggested this is a key gap in enabling more effective mine closure. The current report is an independent document that has been developed by the Western Australian Biodiversity Science Institute (WABSI) with two key aims:

- Review the rehabilitation completion criteria and monitoring knowledge base, and
- Develop a science-based framework for post-mining rehabilitation completion criteria and monitoring.

The report has been developed by leading experts in partnership with representatives from key mining industry and regulatory agencies in Western Australia. The development of the report has been strongly informed by the requirements of the resource sector in order to provide information and a decision support framework that best meets the requirements of:

- Mining companies and service providers operating across all geographic regions in Western Australia;
- Regulatory and policy making agencies of government;
- Public and private research institutions supporting continual improvement.

The report has been designed to extend information provided in best practice guides, such as the Leading Practice Sustainable Development Program (LPSDP) for the *Mining Industry – Mine Closure* handbook (LPSDP 2016d). The intent of the report is to support the development and implementation of completion criteria and associated monitoring programs as outlined in the *Guidelines for Preparing Mine Closure* Plans (DMP & EPA 2015). The guidelines have been developed by the Western Australian Department of Mines and Petroleum (DMP, now Department of Mines, Industry, Regulation and Safety (DMIRS)) and the Environmental Protection Authority (EPA) to meet the respective objectives of the Western Australian regulatory requirements:

> *"The Department of Mines and Petroleum's (DMP) principle closure objectives are for rehabilitated mines to be (physically) safe to humans and animals, (geo-technically) stable, (geo-chemically) non-polluting/ non-contaminating, and capable of sustaining an agreed post-mining land use."*
>
> *"The Environmental Protection Authority's (EPA) objective for Rehabilitation and Decommissioning is to ensure that premises are decommissioned and rehabilitated in an ecologically sustainable manner."*

The Department of Mines, Industry Regulation and Safety (DMIRS) and the EPA require the following information to be included in a Mine Closure Plan:

- Completion criteria that will be used to measure rehabilitation success;
- Completion criteria that will demonstrate the closure objectives have been met; and
- Completion criteria developed for each domain which consider environmental values.

Mine Closure Plans are regularly reviewed over the life of a mine, with updates on the further refinement and development of completion criteria. This provides direction for the monitoring of information required to develop robust criteria and considering trajectory of rehabilitation management actions.

1.2.1 Limitations in scope

Being the first project of its kind and to be completed in a relatively short timeframe, the scope of the project gave priority to guidance in the development of biological completion criteria. Addressing the broader range of completion criteria to a high level of detail was not possible with the time and resources available. The report should be read in conjunction with other materials released by DMIRS and Department of Water and Environmental Regulation (DWER). The process of relinquishment and challenges faced by industry are also not addressed in this document. At the time of publication, additional projects and documents are in development to address some of these knowledge gaps. Updated versions of the report may be warranted in future years to incorporate additional detail towards the non-biological aspects of the framework, relinquishment process and other identified gaps as outlined in Section 6.1.

1.3 How to use the document

This report and the associated framework have been developed with the resource sector as the target audience. However, it is recognised that completion criteria development and monitoring are relevant within other rehabilitation or ecological restoration contexts. The EPA's interest in completion criteria, for example, extends beyond mining projects to other developments such as infrastructure programs that require similar rehabilitation of disturbed lands. While mining is the primary industry identified to use this document, this report and associated framework have been designed to be inclusive of the diverse range of potential activities that may make use of completion criteria guidelines. When using this document to support completion criteria development in different sectors or jurisdictions across Australia and internationally, it is important that users pay close attention to relevant legislation and existing guidance information within their specific context.

The framework presented is intended to be used as a supporting guide to develop completion criteria for mine closure in Western Australia. The procedure proposed is not intended to be a replacement if existing processes are well established and have proven to be successful. The outlined steps to developing completion criteria may be used in their entirety or as individual components to strengthen current practices. The individual processes undertaken by industry to develop site completion criteria should be well documented and available for discussion with regulators and key stakeholders as part of ongoing consultation as a mine progresses towards closure.

This report has two parts. The first part (Chapter 2) presents a new framework to help guide the decision-making process associated with completion criteria development. The second part (Chapters 3, 4 and 5) document current understanding and perspectives on completion criteria development.

The first part presents a decision framework for developing and assessing completion criteria (Chapter 2). The framework is presented as a process consisting of six steps that enable the successful achievement of a post-mining land use. However, the framework is relevant across the life of mine and should be used in an iterative manner, with consideration of completion criteria being initiated during the exploration or approval stage, iterative development, monitoring and refinement of completion criteria across the operational stage and finalisation and assessment of completion criteria as part of the relinquishment and successful transition to next land use. The framework may also be applied spatially, recognising potential variations in closure objectives and completion criteria across a site. Notably, different domains or areas within one single mine site may be capable of achieving different levels of rehabilitation and, thus, will require distinct completion criteria and rehabilitation works. It is also possible that different domains within a single mine could have different post-mining land uses.

Each step in the framework includes key considerations and guidance to inform the decision making and prioritisation process. The decision-making process should be captured when using the framework to develop site-specific criteria. Tools have been provided to support the recording and presentation of information to demonstrate the process used and application to a particular site or domain. A common set of definitions, processes and methods will also help to reduce inconsistencies across regulators, mining companies and consultants in developing completion criteria. For the wider community and environment, a better process for the definition of mine completion criteria will assist in a greater number of mines being completed and, ultimately, relinquished.

The second part of the report includes foundational information that captures the current state of knowledge on completion criteria development. Collectively, the second part provides an important context and directions for users of this guide to consider and learn from when developing completion criteria and risk-based monitoring system development in Western Australia.

Chapter 3 consists of a review of existing guidelines, frameworks and principles for the establishment of completion criteria and associated risk assessment that are available in Western Australia, as well as national or international frameworks applicable to Western Australia. The review presents an assessment of the attributes that may be developed into completion criteria and associated monitoring and evaluation approaches. This provides a valuable reference for informing the development of completion criteria.

The second part also presents the views of stakeholders provided through interviews and surveys within the resource sector (Chapter 4). This provides insights into current understanding and consideration of post-mine land use decisions, completion criteria, risk assessment and monitoring practices, and the process of mine closure planning in Western Australia. The interviews and surveys also highlight the key challenges regulators, mining companies and consulting sector face in the identification and evaluation of completion criteria.

The case studies (Chapter 5) detail the key challenges and decision-making processes at three sites that represent varied environment, mining, and social contexts: Goldsworthy Northern Area (iron ore, BHP Billiton), Tallering Peak (iron ore, Mount Gibson Iron) and Northern Jarrah Forest (bauxite, Alcoa of Australia).

1.4 Terminology and definitions

In this document, the term 'rehabilitation' is defined as the return of disturbed land to a safe, stable, non-polluting/ non-contaminating landform in an ecologically sustainable manner that is productive and/or self-sustaining, and is consistent with the agreed post-mining land use (DMP & EPA 2015). This description fits the general practice of design and construction of landforms and soil profiles together with revegetation as described in the LPSDP handbook (LPSDP 2016e), that is typical of almost all Australian mine sites, and is distinct from 'ecological restoration' (definition in Table 1.1).

A feature of any discussion of completion criteria for mine rehabilitation is the differences in terminology used to describe various elements of a completion criteria framework, or differences in meaning for the same terminology. Predictably, these differences in terminology can be found between different countries and jurisdictions, but also exist between mining operations, and their stakeholders within Western Australia. For this review, we have drawn on language from guidance published by Western Australia (DMP 2016), Queensland (DEHP 2014) and New South Wales (NSW) (TIRE 2013), the Australian LPSDP series (LPSDP 2016d,e) and the National Standards for the Practice of Ecological restoration Australiasia (SERA 2017).

TABLE 1.1 Definitions of key terminology

Term	Definition	Source(s)
Aspect	A key theme or element of rehabilitation that needs to be addressed in order to meet the mine site's closure objectives. Also known as 'Environmental factor'.	Adapted from DMP & EPA 2015
Attribute	A specific parameter that can be quantified, or task that can be verified to have been achieved. Forms the basis for a criterion. Also known as 'Indicator' or 'Performance indicator'.	Adapted from DMP & EPA 2015; McDonald *et al.* 2016
Auditing	The process whereby the site's level of rehabilitation performance – as reflected in the monitoring data - is compared with the standards agreed in the completion criteria.	
Closure	A whole-of-mine-life process, which typically culminates in tenement relinquishment. It includes decommissioning and rehabilitation.	DMP & EPA 2015
Closure objectives	Required outcomes, for each aspect, that will allow return of disturbed land to a safe, stable, non-polluting/ non-contaminating landform in an ecologically sustainable manner that is productive and/or self-sustaining and is consistent with the agreed post-mining land use. Closure objectives should be i) realistic and achievable; ii) developed based on the proposed post-mining land use(s); and iii) as specific as possible to provide a clear indication on what the proponent commits to achieve at closure. They may include, but should not be limited to, compliance, landforms, revegetation, fauna, water, infrastructure and waste.	
Completion	The goal of mine closure. A completed mine has reached a state where mining lease ownership can be relinquished and responsibility accepted by the next land user.	DMP & EPA 2015
Completion criteria	Agreed standards or levels of performance that indicate the success of rehabilitation and enable an operator to determine when its liability for an area is able to cease. A *criterion* is a condition to be achieved for a particular attribute that is critical in achieving the objective. Where possible, criteria should be quantitative and/or capable of objective verification. Also known as 'completion, closure, success or performance criteria', 'indicator', 'standard' or 'target'. Sometimes presented as separate indicator (what to measure) and standard (the level to be achieved).	
Data monitoring	The collection and interpretation of information that is necessary to assess the progress towards meeting completion criteria.	
Ecological restoration	The process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed.	SERA 2017
Monitoring	The observation and checking of the progress or quality of performance over a period of time.	
Objective	See closure objective.	
Post-mining land use (PMLU)	Term used to describe a land use that occurs after the cessation of mining operations.	DMP & EPA 2015
Reference	A suite of conditions that serve to inform the level of performance to be used in the definition of completion criteria. References should provide indication on measurable targets for those attributes that will define completion criteria. For each mine site, one or more references can be used.	

Table 1.1 continues following page...

TABLE 1.1 Definitions of key terminology

Term	Definition	Source(s)
Rehabilitation	The return of disturbed land to a safe, stable, non-polluting/ non-contaminating landform in an ecologically sustainable manner that is productive and/or self-sustaining consistent with the agreed post-mine land use.	DMP & EPA 2015
Relinquishment	A state when agreed completion criteria have been met, government "sign-off" achieved, all obligations under the *Mining Act 1978* removed and the proponent has been released from all forms of security, and responsibility has been accepted by the next land user or manager.	DMP & EPA 2015
Corrective action	Changes made to a nonconforming site to address the deficiency. May also be referred to as 'remedial action' or 'active management'.	ANZMEC & MCA 2000
Revegetation	Establishment of self-sustaining vegetation cover after earthworks have been completed, consistent with the post-mining land use.	DMP & EPA 2015
Verification	The method used to confirm that the identified standard for the criterion has been achieved. Verification may rely on quantitative measurements or could be a process of certification, for example in terms of compliance with an approved design.	

Photo courtesy: Renee Young

2
CHAPTER

2 The completion criteria framework

2.1 Introduction

The purpose of this Chapter is to set out a framework for the definition of risk-based completion criteria and monitoring. The framework has been informed by a review of relevant literature and research; a program of industry (including government) interviews and survey, followed by a workshop; and several case studies (summarised in the following Sections). The aim of the framework is to provide greater consistency for mining companies to develop risk-based completion criteria and monitoring. In addition, it aims to support the regulators by providing greater consistency in the development of mine closure plans across companies, locations and commodities. The framework will also provide a common set of definitions, processes and methods. For the wider community and environment, a better process will assist in leading to a greater number of mines being closed and ultimately, relinquished.

2.2 Framework outline

The framework identifies six key components (Figure 2.1) in the development of, and assessment against, completion criteria: 1) selection of post-mining land uses (PMLUs); 2) aspects and closure objectives; 3) selection of references; 4) selection of attributes and risk-based prioritisation; 5) development of completion criteria; and 6) monitoring. Additional key factors to consider are briefly discussed (e.g. federal and state planning, change management, learnings and innovation, consideration of offsets). Within each major component, several sub-steps are also required (Figure 2.2).

In some cases, the framework may be used as a linear pathway to develop risk-based completion criteria, whereas in others, it may be more appropriate to consider and develop a number of the components consecutively, or in an alternate order. Examples of the different approaches to using the framework are presented in Figure 2.1. For clarity and consistency, this document presents the framework as the linear process (Figure 2.1a) but acknowledges that the development of completion criteria, and monitoring progress towards achieving them, is an iterative process that involves multiple stakeholders and continuous refinement, measurement and re-definition along the lifecycle of a mine. The framework also allows for application across multiple spatial domains within a mine site, recognising that in some situations different potential PMLUs, closure objectives and completion criteria may be developed across a single site.

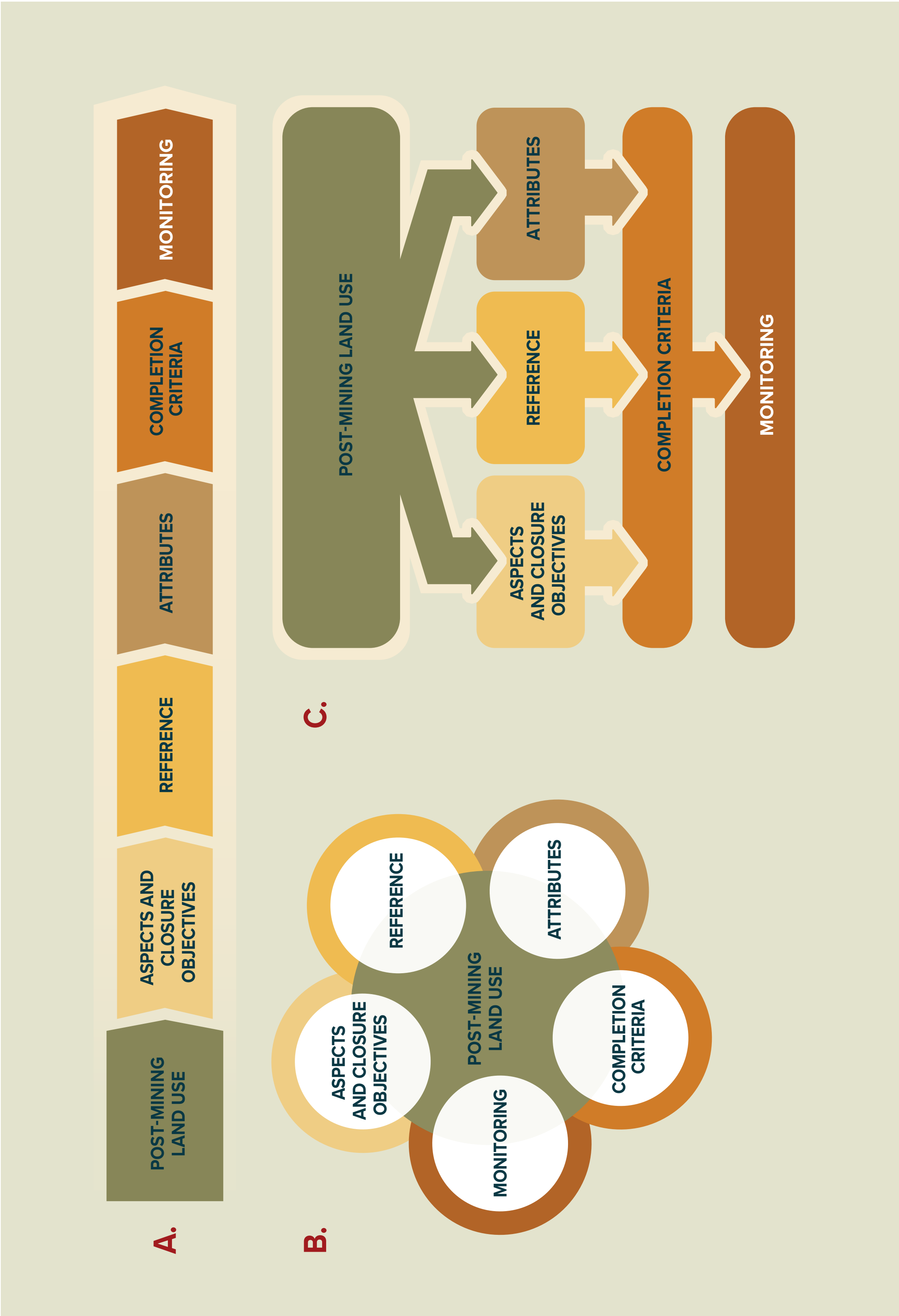


FIGURE 2.1 Six key components to the development and assessment against completion criteria. a) Linear process, b) Consecutive approach, c) Combination of linear and consecutive approach.

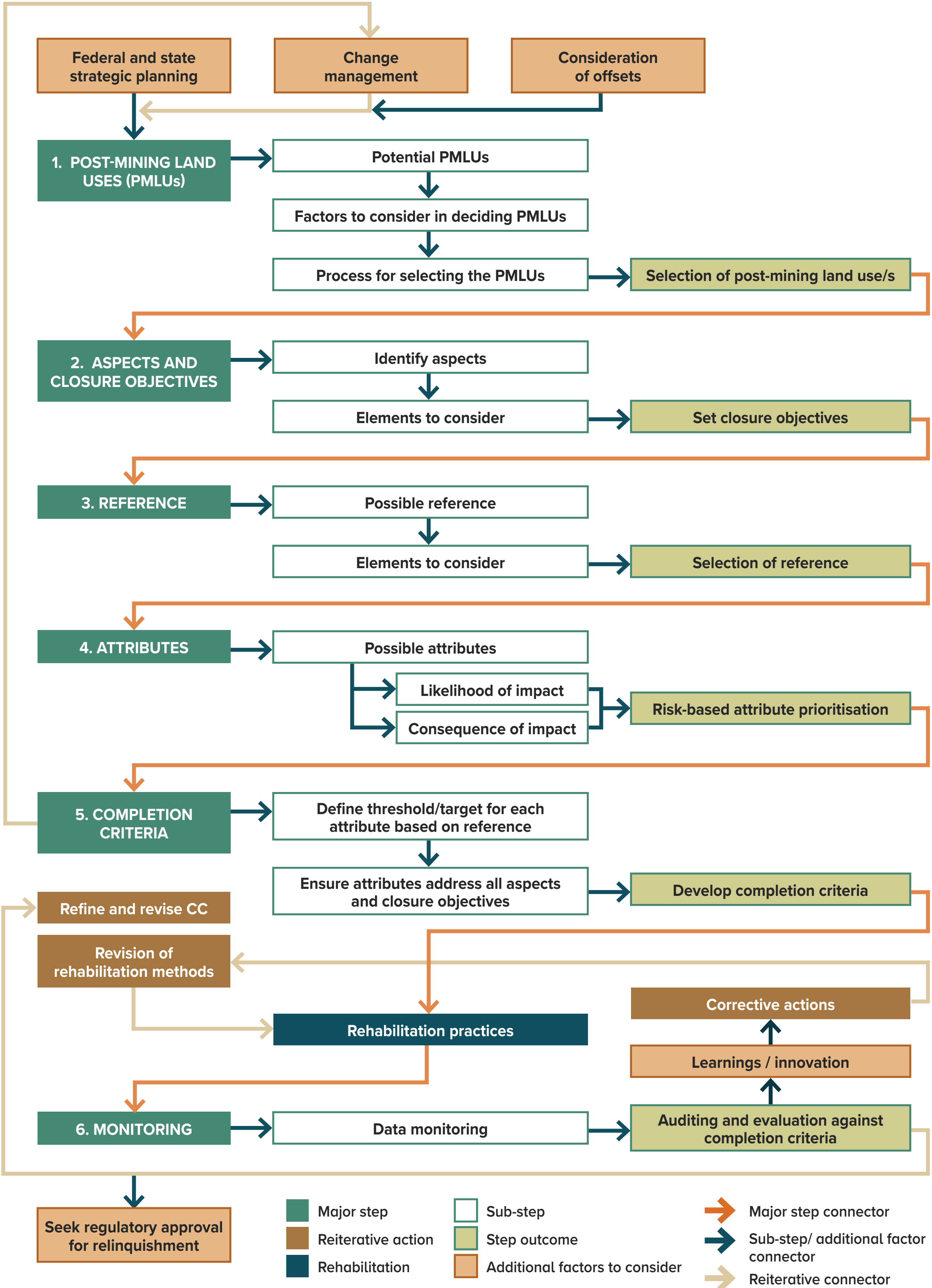


FIGURE 2.2 Framework for the definition of completion criteria (linear approach)

2.3 Federal and state planning

Prior to the definition of site-specific completion criteria, it is important to establish if there is any federal or state strategic planning over the covenanted area that may dictate what the PMLUs will be. If not already understood, mining proponents should inform themselves about strategic land planning schemes through consultation with DMIRS, DWER, EPA and DPLH. In Western Australia, this may include but not be limited to DMIRS, DWER & EPA; DPLH as well as relevant development commissions and local councils.

2.4 Component 1 – Post-mining land uses (PMLUs)

The PMLUs need to be considered early on in the planning stage, and it is recommended that they are identified and agreed upon before approval of new projects (DMP & EPA 2015). While the most common PMLU for Western Australian mines is to revert to pre-mining land use (Chapter 4 Interviews and Survey), such selection should be based on a thorough examination of all possible options. Alternative post-mining land uses should not be ruled out, as it may achieve a beneficial outcome for the key stakeholders in some circumstances. Where the opportunity presents, mining companies may also consider repurposing the use of the land for other beneficial uses if the legislation allows and relevant stakeholders and regulators agree. Hence, this framework proposes that PMLUs are selected through a process involving three steps: identification of potential PMLUs; factors to consider in the selection of PMLUs; and a systematic decision-making process. Early-stage processes may consider multiple PMLUs scenarios within the framework as part of an approach that provides greater flexibility, as it does not preclude the change of one PMLU to another.

2.4.1 Potential PMLUs

At the early stages of mine closure planning, all potential PMLUs should be considered. State, national and international guidelines (DEHP 2014; DMP & EPA 2015; Heikkinen *et al.* 2008), as well as academic articles (Cowan *et al.* 2010; Kaźmierczak *et al.* 2017) prescribe a series of requirements that PMLUs should fulfil. While there is not one set of commonly accepted guidelines, there is consistency in proposing that PMLUs must be:

- Relevant to the tenure;
- Relevant to the environment where the mine operates, considering, for example, natural conditions, terrain configuration, vegetation and water bodies;
- Considerate of historical commitments at the site and at a regional scale;
- Achievable in the context of land capability and safeguarded against physical, chemical and biological hazards;
- Acceptable to key stakeholders, including regulators, local authorities and indigenous groups;
- Ecologically sustainable and, where appropriate, economically productive; and
- Within any other legislative constraints.

Based on the review undertaken and consultation with stakeholders, this framework proposes the use of the Australian Land Use and Management (ALUM) classification (ABARES 2016) for the definition of PMLUs (summarised in Table 2.1). This has several advantages. First, it provides a comprehensive and concise definition of land uses. Second, it makes the definition of PMLUs consistent with other land planning institutions, not only in Western Australia, but also applicable across Australia. Third, as definitions of land use change overtime, this framework will always remain up-to-date by referring to the latest ALUM classification, which is periodically updated.

Photo courtesy: Stacey Williams

The ALUM classification system provides a nationally systematic, logical and consistent method to present land use information across Australia in a hierarchical structure. There are six primary classes of land uses included in the classification: conservation and natural environments; production from relatively natural environments; production from dryland agriculture and plantations; production from irrigated agriculture and plantations; intensive uses; and water. The hierarchical system identifies the minimum level of classification required, but also allows higher level of land use to be assigned if appropriate — see Figure 1 in ABARES (2016). The classification system supports the classification of land for users that are interested in process and outputs as well as allocation of primary and ancillary land uses. At times, there may be mine features that are unable or highly unlikely to have a beneficial next land use. The ALUM classification also provides a categorisation for this, 'Extractive Industry not in use', which may be appropriate for certain areas within a site. Areas assigned to this class would need to be justified, accurately defined and, as with other PMLUs, agreed upon with regulators and stakeholders. There may also be PMLUs that are desirable, but not specifically listed under the ALUM classification. In these scenarios, the PMLU can still be proposed with the most appropriate ALUM class assigned and then further detail provided to stakeholders and regulators as appropriate (e.g. carbon farming could be classified under, 'production native forests, other forest production', in Table 2.1 below).

TABLE 2.1 Summary of Australian Land Use and Management classification

Primary class	Definition	Secondary classes
1. Conservation and Natural Environments	Conservation purposes based on maintaining the essentially natural ecosystems present.	Nature conservation; Managed resource protection; Other minimal use
2. Production from Relatively Natural Environments	Primary production with limited change to the native vegetation.	Grazing native vegetation; Production native forests
3. Production from Dryland Agriculture and Plantations	Primary production based on dryland farming systems.	Plantation forests; Grazing modified pastures; Cropping; Perennial horticulture; Seasonal horticulture; Land in transition
4. Production from Irrigated Agriculture and Plantations	Primary production based on irrigated farming.	Irrigated plantation forests; Grazing irrigated modified pastures; Irrigated cropping; Irrigated perennial horticulture; Irrigated seasonal horticulture; Irrigated land in transition
5. Intensive Uses	Land subject to extensive modification, generally in association with closer residential settlement, commercial or industrial uses.	Intensive horticulture; Intensive animal production; Manufacturing and industrial; Residential and farm infrastructure; Services; Utilities; Transport and communication; Mining; Waste treatment and disposal
6. Water	Water features.	Lake; Reservoir; River; Channel/aqueduct; Marsh/wetland; Estuary/coastal waters

Source: ABARES 2016

2.4.2 Factors for selecting PMLUs

The Western Australian Guidelines for Preparing Mine Closure Plans (DMP & EPA 2015) provide a hierarchical guide that prioritises natural ecosystems before alternative land uses. While the majority of mine closure plans in Western Australia follow such instruction (MINDEX 2017), sometimes the previous land use is no longer achievable or appropriate. In such situations, setting unrealistic goals against unachievable PMLUs may lead to poor closure standards being achieved and an inefficient use of resources (McCullough, 2016). Thus, when selecting the PMLUs, it is critical to take into consideration all elements that may constrain or favour the various PMLUs options. Once formal approval has been obtained, industry is legally obliged to comply with that requirement. A summary of factors to be considered in the selection of PMLUs is presented in Table 2.2.

TABLE 2.2 Factors to consider in the selection of PMLUs

Factors	Definition
Land tenure	Existing land tenure that specifies what the PMLUs will be.
Legislative constraints	Conditions pertaining to any relevant legislation and Acts.
Strategic planning	Local and regional land planning schemes by relevant authorities such as Department of Primary Industries and Regional Development; Department of Planning, Lands and Heritage; Pilbara Development Commission.
Pre-mining conditions	Conditions of the area prior to mining.
Acceptability to key stakeholders	Feedback received through continuous stakeholder engagement.
Heritage (natural, cultural or historical)	Impact associated with the PMLUs on heritage and agreement with relevant government departments and stakeholders.
Physical, chemical and biological hazards (anthropogenic and naturally occurring)	Hazardous materials, unsafe facilities, contaminated sites, radioactive materials, among others.
Consistency with other mines in the area	PMLUs proposed by other nearby mines where applicable and justified as the most acceptable approach.
Compatibility with surrounding area	Integration of the PMLUs with the surrounding landscape in terms of aesthetics, land capability, etc. taking into account the changes occurred over the life of mine.
Feasibility/viability	PMLUs should be achievable in the context of post-mining land capability.
Added value	Value generated as a result of the PMLUs.

2.4.3 Processes for selecting the PMLUs

Existing frameworks in Australia (ANZMEC & MCA 2000; DMP 2016; LPSDP 2016d) indicate that PMLUs should be agreed through consultation with key stakeholders and must take into account any existing obligations or commitments made. These conversations should be informed by a decision-making process to identify the most suitable PMLUs (Table 2.3). There are a number of decision-making frameworks available to assist in this process including Multi-Attribute Decision-Making (MADM) and Mined Land Suitability Analysis (MLSA), Benefit-Cost Analysis (BCA), Land capability assessment (LCA)/Land suitability assessment (LSA) or Ecosystem Services Assessments (ESA) (Table 2.3).

Decision-making frameworks for selecting PMLUs may integrate a variety of environmental, social or economic values. These may range, for example, from local priorities to overall societal welfare. Certain methods, like LCA or ESA, are more focussed on environmental and ecosystem values, while stakeholder consultation tends to prioritise socio-economic considerations. MADM and BCA allow the incorporation and weighting of the multiple values impacted by PMLUs. More detailed descriptions of each of these decision-making processes, along with supporting references, are provided in the science and governance review, Chapter 3.

TABLE 2.3 Approaches for the selection of PMLUs

Decision-making processes	Definition
Direct consultation with stakeholders and regulators	PMLUs selected in accordance with stakeholders' preference and/or policy requirements
Multi-attribute decision-making (MADM) and Mined Land Suitability Analysis (MLSA)	Systematic methodology to evaluate, compare and rank project alternatives against a set of criteria. Criteria-weighting and options-evaluation are often carried out using analytical hierarchy process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)
Benefit-Cost Analysis (BCA)	A transparent and systematic decision-making framework to evaluate all the costs and benefit impacts of a project on society. By expressing all impacts in the same unit, the positive and negative effects of a project can be compared
Land capability assessment (LCA) or Land suitability assessment (LSA)	A five-class system based the capacity of land to sustain specific land uses such as cropping, irrigated agriculture and forestry
Ecosystem Services Assessments (ESA)	Evaluation of the conditions and processes through with natural ecosystems, and the species that make them up, sustain and fulfil human life. Categorises ecosystem services in supporting, provisioning, regulating, and cultural services

2.4.4 Consideration of offsets

An environmental offset is an offsite action or actions to address significant residual environmental impacts of a development or activity. An offset can either be direct (an action designed to provide for on-ground improvement, rehabilitation and/or conservation of habitat) or indirect (actions aimed at improving scientific or community understanding and awareness of environmental values that are affected by a development or activity) (Government of Western Australia 2011). Environmental offsets may be factored into the approvals process and, thus, are a key consideration for the selection of the PMLUs. Offsets in the form of on-ground management include revegetation (establishment of self-sustaining vegetation cover) and restoration (the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed) (Government of Western Australia 2014; McDonald *et al.* 2017). The objective of environmental offsets through on-ground management actions result in tangible improvement to environmental values in the offset area and thus may be correlated to the PMLUs for that area if it falls within a mining company's tenement.

2.5 Component 2 – Identifying aspects and defining closure objectives

2.5.1 Identifying aspects

ASPECT: An aspect is a key theme or element that needs to be addressed during closure.

Following selection of the PMLUs, aspects relevant to a site need to be identified for closure objectives to be developed. A typical mine site in Western Australia may identify 10–15 relevant aspects, while complex sites may require more. Aspects may include, but are not limited to, those as listed in Table 2.4, e.g. compliance, landforms, revegetation, fauna, water, infrastructure and waste.

2.5.2 Defining closure objectives

CLOSURE OBJECTIVE: Closure objectives provide a clear indication on what the proponent commits to achieve at closure.

The closure objectives can be developed once the aspects have been identified. Closure objectives define the closure outcomes and should be i) realistic and achievable; ii) developed based on the proposed PMLUs; and iii) as specific as possible to provide a clear indication on what the proponent commits to achieve at closure (DMP & EPA 2015). An example of a closure objective for each aspect is provided in Table 2.4, but it emphasised that each closure objective developed should appropriately detailed to address pertinent issues for the specific site. Examples provided should not be interpreted to be the default for the closure objective. Multiple closure objectives may be required for each aspect and an aspect may be relevant for more than one closure objective.

The compiled set of aspects and closure objectives developed should be site specific and able to satisfy that the site is safe, stable, non-polluting and able to support the agreed end land use, covering all major considerations for mine closure and relinquishment.

TABLE 2.4 Examples of aspects and closure objectives

Aspect	Closure objective
Social	Actively engaged and consulted key stakeholders that have agreement on the post-mining land use.
Physical and surface stability	Creation of safe and stable landform that minimises erosion and supports vegetation.
Mine wastes and hazardous materials	Achieve conditions where contaminants of the site are consistent with the final land use requirements. Minimise the potential for off-site pollution.
Water and drainage	Surface drainage patterns are reinstated and consistent with the regional drainage function.
Soil fertility and drainage	Suitable growth medium is in place to facilitate rehabilitation and agreed post-mining land use.
Flora and vegetation	Restored landscapes that are comparable to reference vegetation communities established through leading practice restoration techniques and within the constraints of the post-mining environment.
Ecosystem function and sustainability	The rehabilitated ecosystem has function and resilience indicative of target ecosystem.

2.6 Component 3 – Establishing a reference

REFERENCE: A suite of conditions that serve to inform the level of performance to be used in the definition of completion criteria.

Once the PMLUs, aspects and closure objectives have been identified, it is necessary to select the reference against which completion criteria will be defined. Data collected from references is used to inform the attributes and standards required for the development of the completion criteria. In addition, such data will be used to demonstrate progress towards meeting completion criteria throughout closure and rehabilitation works. It is important to note that the reference informs the definition of completion criteria by providing an objective assessment of attribute states relevant for PMLUs, but the selection of references is independent of the standard applied in the completion criteria. Reference assessment indicates how attributes perform under reference states, while standard is usually an agreed value expressed relative to these. Approaches to determining the relative values of the reference that will be employed as the completion criterion are described in Section 2.8. Depending on the PMLUs and the specific site, several different approaches to reference identification and use may be suitable (Table 2.5). Relevant to the case of mine sites returning to pre-mining land use, McDonald *et al.* (2017) provide further details on the selection of a reference ecosystem that is based on an actual site or conceptual model.

Pre-disturbance conditions may often be an appropriate reference and thus, can be used when the necessary information is available. Baseline survey information, however, may not reflect current or future conditions within the mine life cycle, and a principle of completion criteria development is that the change in the nature of the site as a result of mining is acknowledged. If sufficiently detailed baseline data is not available, an appropriate analogue site should be identified. The analogue site is an intact area (or combination of areas) that reflects the desired closure outcomes of the mine site. These may include, for example, adjacent or near-by ecosystems of the same vegetation type, other mining sites with similar characteristics or existing areas with the same agreed PMLUs that have achieved the agreed objective and completion criteria.

In cases when baseline conditions and analogue sites are not available or appropriate, alternative methods may be used. For example, reference conditions that can be defined based on closure outcomes that can be achieved using leading practices. Such conditions are defined based upon laboratory experiments, in situ field trials, industry standards and best-available rehabilitation techniques. Importantly, references based on leading practices must be evidence based and ascertain that the benchmarks are demonstrable examples of best practice and outcomes. In these circumstances, mining proponents must provide sufficiently detailed information regarding which best practices they intend to adopt and how these will be carried out at the specific mine site. The selection of best practices and expected rehabilitation outcomes must be justified to the level of detail and accuracy that will satisfy regulators' requirements.

Particular challenges exist for pit lakes, which are unlikely to have relevant references or analogues due to their depth, bathymetry and/or catchment area. Solutions to this challenge are only starting to be developed (Blanchette & Lund 2016). Relevant references or analogues for river diversions and modified rivers are difficult to find due to high local variability and cumulative impacts. A proposed approach to filling this knowledge gap is provided in Blanchette & Lund (2017) and Blanchette *et al.* (2016).

When the PMLUs are not for conservation or natural environments, a reference may be defined based on a site of the same designated PMLUs. An example may be a residential development of renewable energy plant, which can serve as models for the rehabilitated site post-mining.

Importantly, more than one reference may be used to inform the definition of completion criteria, where justified. It is possible that performance levels for certain attributes are mirrored in one set of references (e.g. groundwater quality in baseline conditions), yet other elements find a more appropriate reference elsewhere (e.g. vegetation cover based on 'leading practice'). Thus, conceptual models are synthesis of several references, including analogue sites, field indicators, historical data and trajectory models.

Mine closure plans should include documentation and justification of the processes used in the identification and selection of references. This documentation should include how and why a decision was identified to be more appropriate than other alternatives.

TABLE 2.5 Possible reference for post-mining land use

References	Definition
Baseline conditions	Conditions present at the site prior to mine use.
Analogue site	Adjacent or near-by sites from which the necessary attributes to can be quantified to develop completion criteria for the sites agreed upon PMLUs.
Leading-practice outcome	The conditions that most closely define the values desired for the site and that can be realistically achieved. Such conditions are defined based on laboratory trials, on-site trials, basis of design, industry standards and demonstrated effective leading-practice techniques.
Other alternative sites	Example sites for alternate PMLUs, such as renewable energy farm or residential development.
Conceptual model	Synthesis of several data-based references including existing sites, field indicators and historical and predictive records.

Photo courtesy: Dean Revell

2.7 Component 4 – Attributes

2.7.1 Attribute identification

ATTRIBUTE: A specific parameter that can be quantified, or task that can be verified to have been achieved.

A large number of attributes may be used in the definition of completion criteria (see review in Chapter 3), with this framework presenting a sub-selection of those most recommended (Table 2.6), given their ease of monitoring and adequacy as rehabilitation performance indicators. While extensive, the lists provided are not exhaustive and additional attributes may be appropriate, based on specific site requirements.

In the development of a MCP, Table 2.6 may serve as a reference for proponents to select those attributes that are specifically relevant to their particular mine site. Selected attributes should be measurable and their metrics comparable to the targets derived from the reference. While attributes are grouped relative to aspects, it should be noted that certain attributes may be relevant to more than one aspect, e.g. slope of waste dumps may affect drainage, waste and physical stability. Consequentially, a single attribute may provide evidence towards multiple closure objectives, whilst several attributes may be required to demonstrate progress towards a single closure objective.

TABLE 2.6 Recommended attributes applicable for the definition of completion criteria*

Aspect	Possible attributes	Type**
Water and drainage	Design and construction of landforms and drainage features	P
	Quality, quantity and fate of surface water flow	Q
	Integrity of drainage structures	Q/C
	Connectivity with regional drainage (lakes & rivers)	Q
	Pit lake bathymetry	P/Q
	Pit lake sediment quality	Q
	Pit lake water quality	Q
	Surface water quality, quantity and timing	Q
	Surface water chemistry and turbidity	Q
	Aquatic biota (algae, macrophytes; invertebrate and vertebrate fauna)	Q
	Riparian vegetation	Q
	Surface water chemistry and turbidity	Q
	Groundwater chemistry	Q
Mine waste and hazardous materials	Landform design and construction	P
	Particle size and erodibility	Q
	Strength	Q
	Acid, alkali or salt production potential	Q
	Total and soluble metals and metalloids	Q
	Spontaneous combustion potential	Q
	pH and electrical conductivity	Q
	Radiation	Q
	Asbestiform minerals	Q/P
	Design and construction of containment structures for hostile wastes	P
	Physical integrity of containment structures for hostile wastes	Q
	Dust	Q
	Sediment quality	Q
Physical and surface stability	Soil coarse fraction content	Q/P
	Soil fraction particle size analysis (texture)	Q
	Hydraulic conductivity	Q
	Sodicity, slaking and dispersion	Q
	Soil strength	Q
	Surface resistance to disturbance	Q
	Erosion rills, gullies, piping	Q
	Sediment loss	Q
	Placement of appropriate surface materials	P/Q
	Earthworks as designed	P
Soil fertility and surface profile	Bulk density, depth of ripping and soil strength	Q/P
	Aggregate stability	Q
	Water infiltration	Q
	Plant-available water	Q
	Soil profile as designed	P/Q
	Electrical conductivity	Q
	Nutrient pools (N, P, K, S)	Q
	Plant-available nutrients; cation exchange capacity	Q
	Heavy metal bioavailability	Q

Table 2.6 continues following page...

TABLE 2.6 Recommended attributes applicable for the definition of completion criteria*

Aspect	Possible attributes	Type**
Flora and vegetation	Numbers of species and quantities of viable seed in seed mix	P
	Number of seedlings planted	P
	Vegetation cover	Q
	Species richness	Q
	Vegetation composition	Q
	Litter cover	Q
	Presence/abundance of keystone, priority or recalcitrant species	Q/C
	Presence of key functional groups	Q/C
	Community structure – presence of all strata	Q/C
	Weed species presence and abundance	Q/C
	Aquatic biota (algae, macrophytes; invertebrate and vertebrate fauna)	Q
	Riparian vegetation establishing	Q
Flora / fauna	Constructed habitat features (breeding and refuge)	P
	Vegetation and litter habitat (foraging, breeding and refuge, in general or for conservation significant species)	Q
	Presence of keystone or significant species	Q/C
Ecosystem function and sustainability	Rainfall capture and infiltration	Q
	Soil microbial function – solvita, respiration	Q
	Presence of different successional groups	Q/C
	Indicator species group richness and composition	Q
	Plant growth, survival, rooting depth, physiological function	Q
	Plant species reproduction and recruitment: flower, seed production, seedbanks	Q
	Capability for self-replacement: seedbanks, seedlings mature 2nd generation	Q
	Connections with nearby systems in place, functioning: corridors; pollinator, gene movement	Q/P
	Key threats absent or managed: feral grazers, predators, pathogens, weeds, etc.	Q/C/P
	Resilience to disturbance (such as fire, drought, extreme weather events)	Q
Social / economic	Recreation opportunities provided, maintained	P
	Heritage values protected	P
	Aesthetics (visual amenity)	P
	Access and safety	P
	Infrastructure removed	P
	Sustainability of utilities	P
	Social progress: health, education, employment, livelihoods and incomes	P/Q

* Not all possible attributes are appropriate for every site, and other attributes not listed may be appropriate. See Table 3.7 for expanded list and sources.

** **Type:**

P = installed/built as planned – a process for emplacing these attributes is approved initially and then certified as and when constructed;

C = categorical – the feature is required to be present or absent;

Q = quantitative – the attribute can be measured and compared against a numerical target.

2.7.2 Risk-based attribute prioritisation

Early stages of mine closure planning should consider a broad range of attributes relevant for the definition of completion criteria. Given that completion criteria should be site specific, not all possible attributes will be used at every site. Among those attributes that are deemed relevant for the definition of completion criteria, some attributes may be more critical than others by posing a greater risk to the fulfilment of closure objectives. This section presents a risk-based attribute prioritisation process, which provides a systematic tool for decision making aimed at a) discerning which attributes should be used to define completion criteria and b) ranking the criticality of selected attributes.

In some instances, the risk-based prioritisation process may rank attributes as very 'low priority', meaning that the attribute poses no, or very low, risk to the fulfilment of closure objectives. In such cases, subject to agreement from the regulator, these may be excluded from the list of completion criteria. An example may be 'impact on heritage' in an area where no heritage sites exists.

On the other hand, those attributes that may pose a risk to the fulfilment of closure objectives as a result of mining activities should be considered in the definition of completion criteria. While companies have an obligation to meet their agreed completion criteria, it is important to recognise that some criteria may be more critical than others. In order to develop an efficient and effective suite of completion criteria, it is advisable that such efforts are prioritised based on the criticality of each attribute. Thus, attributes identified as 'high priority' should be monitored and audited with a greater level of detail and higher frequency compared to 'medium or low priority' attributes. As an example, a mine site could be within a river catchment that supports a rich community of water-dependent ecosystems where the PMLU is nature conservation. The site may, thus, be subject to completion criteria based on 'surface water quality' and 'construction of fauna habitat features'. Both heavily polluted surface water and an insufficient number of habitat features would result in failure to meet completion criteria. Nonetheless, the former poses a much greater risk for closure outcomes i.e. the site being non-polluting and able to support a self-sustaining, agreed PMLU.

The risk-based prioritisation process also provides an opportunity to consider individual attributes and completion criteria within the context of closure objectives being met and a holistic understanding of rehabilitation success. In response to this need, this section proposes a method for attribute prioritisation, based on a systematic, risk-based ranking system. As the Life of Mine (LoM) progresses, the criticality of attributes is likely to change and, thus, the risk-based ranking should be periodically re-assessed.

> **The priority of each attribute is defined based upon *the risk of the attribute preventing the fulfilment of the closure objective*.**

Photo courtesy: DBCA

An example of the attribute prioritisation process follows the structure of commonly used risk management approaches (ISO 2018; LPSDP 2016g) where risk levels are categorised through a matrix of maximum reasonable likelihoods and consequences. Likelihoods and consequences are rated on a 1–5 scale (e.g. rare to almost certain and insignificant to catastrophic, respectively), based on qualitative and semi-quantitative parameters. Several guidelines (Australian Government 2014; LPSDP 2016g) and international standards, such as ISO 31000 (ISO 2015, 2018), provide generic frameworks for identification and management of risks using the likelihood-consequence method. Because risk should be evaluated based on specific circumstances, there are no universal definitions of qualitative ratings (e.g. likely) or thresholds for semi quantitative indicators (e.g. frequency of occurrence).

Therefore, for the purpose of risk-based attribute prioritisation, the definition of likelihood and consequences levels should be specific to each attribute type, and in accordance with international standards listed above, as well as the company's own risk management policies. Examples of definitions of risk likelihood (Table 2.7), consequence (Table 2.8) and categorisation (Table 2.9) are provided below. The risk rating of each attribute provides an indication of the level of detail required in the definition of completion criteria and the type and intensity of monitoring required (Table 2.10). An example of the risk-based attribute prioritisation is provided in Table 2.12. The tables provided below should be reviewed and considered if they are appropriate for a particular site. Currently, there is no standardised risk rating specifically defined towards fulfilment of mine completion criteria — although this may warrant development, as discussed in Section 6.1. Additional examples of risk frameworks can be found in DMP & EPA (2015) *Guidelines for Preparing Mine Closure Plans* and *LPSDP Risk Management* (LPSDP 2016g).

TABLE 2.7 Example of the definitions of likelihood levels for attribute prioritisation

Level	Rating	Description	Probability of occurrence	Frequency of occurrence
5	Almost Certain	Common or frequent event; expected/ proven to occur in most circumstances	> 90%	Monthly occurrence
4	Likely	Has been known to occur; expected/ proven to occur in many circumstances	50 to 90%	Yearly occurrence
3	Possible	Has happened in the past; expected/ proven to occur in some circumstances	20 to 50%	1 in 10 year occurrence
2	Unlikely	Not likely to occur; expected/proven to occur in infrequent circumstances	1 to 20%	1 per 25 year occurrence
1	Rare	Very rare; expected/proven to occur in under rare circumstances	≤ 1%	1 per 100 occurrence

Photo courtesy: DBCA

TABLE 2.8 Example of the definitions of consequence by attribute type

Risk type	Specific risk type	1 – Insignificant	2 – Minor	3 – Moderate	4 – Major	5 – Catastrophic
Health and Safety	Minor injury or illness (first aid or medical treatment)	< 10 individuals	< 100 individuals	< 1,000 individuals		
	Major injury or illness (Medium term, largely reversible); Restricted work injury; Lost Time Injury < 2 weeks	1 individual	< 10 individuals	< 100 individuals	< 1,000 individuals	
	Serious bodily injury or illness (e.g. fractures) and/or Lost Time injury > 2 weeks			1 individual	< 10 individuals	> 10 individuals
	Fatality; or severe irreversible disability (Permanent Disabling Injury) or illness				1 individual	> 1 individual
Legal and compliance		Minor legal issues, non-compliances and breaches of legislation	Breach of legislation with investigation or report to authority with prosecution and/or moderate fine possible	Major breach of legislation with punitive fine. Significant litigation involving many weeks of senior management time	Major litigation costing $10m+. Investigation by regulatory body resulting in long-term interruption to operations. Possibility of custodial sentence	Major litigation or prosecution with damages of $50m. Custodial sentence for company Executive. Prolonged closure of operations by authorities
Property/ infrastructure	Cost to repair/ replace (and lost revenues)	Approximate range from $0 to $0.1 million	Approximate range from $0.1 to $1 million	Approximate range from $1 to 10 million	Approximate range from $10 million to $100 million	Approximate range from $100 million to $1 billion
Environmental	Environmental impact	Negligible reversible environmental impact requiring very minor remediation	Minor reversible environmental impact requiring minor remediation	Moderate, reversible environmental impact with short-term effect requiring moderate remediation	Serious environmental impact with medium term effect requiring significant remediation	Disastrous environmental impact with long-term effect requiring major remediation

Table 2.8 continues following page...

TABLE 2.8 Example of the definitions of consequence by attribute type (cont'd.)

Risk type	Specific risk type	1 – Insignificant	2 – Minor	3 – Moderate	4 – Major	5 – Catastrophic
Environmental ***(continued)***	Ecosystem function	Alteration or disturbance to ecosystem within natural variability. Ecosystem interactions many have changed but it is unlikely that there would be any detectable change outside natural variation occurrence	Measurable changes to the ecosystem components without a major change in function (no loss of components or introduction of new species that affects ecosystem function). Recovery in < 1 year	Measurable changes to the ecosystem components without major change in function (not loss of components or introduction of new species that affects ecosystem function). Recovery in 1-2 years following completion of Project construction	Measurable changes to the ecosystem components with a major change in function. Recovery (i.e. within historic natural variability) in 3 to 10 years following completion of Project construction	Long-term and possibly irreversible damage to one or more ecosystem functions. Recovery, if at all, greater than 10 years following completion of Project construction
	Habitat or communities	Altercation or disturbance to ecosystem within natural variability. Area of habitat affected or removed <1 %	Reestablishment in < 1 year. Area of habitat severely affected or removed < 5 %	Reestablishment in < 2 years. Area of habitat severely affected or removed < 30 %	Reestablishment in < 10 years. Area of habitat severely affected or removed <90%	Reestablishment in > 10 years. Area of habitat severely affected or removed > 90%
	Species and/or groups of species (including protected species)	Population size or behaviour may have changed but it is unlikely that there would be any detectable change outside natural variation/occurrence	Detectable change to population size and/or behaviour, within no detectable impact on population viability (recruitment, breeding, recovery) or dynamics. Recovery < 1 year	Detectable change to population size and/or behaviour, within no detectable impact on population viability (recruitment, breeding, recovery) or dynamics. Recovery < 2 years	Detectable change to population size and/or behaviour, within no detectable impact on population viability (recruitment, breeding, recovery) or dynamics. Recovery < 10 years	Local extinctions are imminent/immediate or population no longer viable. Recovery > 10 years

Table 2.8 continues following page...

TABLE 2.8 Example of the definitions of consequence by attribute type

Risk type	Specific risk type	1 – Insignificant	2 – Minor	3 – Moderate	4 – Major	5 – Catastrophic
Social	Amenity – Recreation (water sports. Fishing, beach going)	Short-term interruptions in recreational use (1-2 days)	Restricted activities within a localised area for short periods (months)	Communities totally or partially restricted from recreational activities for up to 2 years	Communities totally or partially restricted from recreational activities for 2 to 10 years	General community unable to pursue recreational activities for over 10 years
	Amenity- Sensory/Perception (visual, noise, odour)	Short-term (<1 year) impact on the perceived amenity of the site as a place to live or visit. The region's attractiveness as a place to live is not changed	Short-term (<1 year) impact on the perceived amenity of the site as a place to live or visit. The region's local attractiveness as a place to live is negatively changed	Medium term (1-2 years) impact on the perceived amenity of the site as a place to live or visit. The region's wide attractiveness as a place to live is negatively changed	Long-term (>2 years) community perception that the area is significantly damaged. The region's wide attractiveness as a place to live is negatively changed	Very long term (>10 years) community perception that the area has experienced major damage and has become a place to be avoided
	Media coverage and public reaction	No media coverage. No community complaints	Local media coverage. Complaint to site and/ or regulator	Local media coverage over several days. Persistent community complaints	National media coverage over several days. Community / NGO legal actions	Prominent negative International media coverage over several days
	Company's reputation and local economy	No impact	No impact	Negative impact on local economy	Significant negative impact on share price for weeks. Impact on local economy	Significant negative impact on share price for months
	Non-aboriginal heritage within State/Commonwealth site	No measurable alterations to existing natural or human processes already impacting on heritage sites	Detectable impact with heritage values remaining largely intact	Partial reduction in intrinsic heritage value	Substantial reduction in intrinsic heritage value	Complete loss of heritage intrinsic value
	Non-aboriginal heritage within non-State/Commonwealth site	No measurable alterations to existing natural or human processes already impacting on heritage sites	Partial reduction in intrinsic heritage value	Substantial reduction in intrinsic heritage value	Complete loss of heritage intrinsic value	

Table 2.8 continues following page...

TABLE 2.8 Example of the definitions of consequence by attribute type

Risk type	Specific risk type	1 – Insignificant	2 – Minor	3 – Moderate	4 – Major	5 – Catastrophic
Social ***(continued)***	Aboriginal heritage	No measurable alterations to existing natural or human processes already impacting on Indigenous heritage sites	Partial removal of one or more Indigenous archaeological sites in a specific area within the mine site	Complete removal of one or more Indigenous archaeological sites in a specific area within the mine site	Complete removal of multiple Indigenous archaeological sites in several areas within the mine site	Complete removal of multiple Indigenous archaeological sites across the entire mine site
	Tourism	Limited and short-term (<1 year) reduction in tourist visits with no impact on local businesses	Short-term (<1 year) reduction in tourism use	Medium term (2-10 years) reduction in tourism use	Permanent reduction in tourism use with businesses viability becoming compromised	Permanent loss of attractiveness as a tourist site with significant negative impact on local businesses
	Cost to property (AUD)	<10k	10k – 300k	300k – 2m	3m – 30m	30m

Source: Adapted from LPSDP (2016g)

Photo courtesy: Lesley Gibson

TABLE 2.9 Example of qualitative risk rating matrix

Likelihood		Consequence: 1 Insignificant	2 Minor	3 Moderate	4 Major	5 Catastrophic	Risk rating
5	Rare	VL1	VL2	L3	M5	M10	Very Low
4	Unlikely	VL2	L4	L6	M7	H11	Low
3	Possible	L3	L6	M9	H12	H15	Moderate
2	Likely	L4	M8	H12	H16	E20	High
1	Almost certain	M5	M10	H15	E20	E25	Extreme

TABLE 2.10 Relevant actions based on attribute risk rating

Risk rating	Action relevant to management of risk[1]	Action relevant to completion criteria and monitoring
Extreme	Immediate action and formal documentation required. This level of risk is not tolerable, senior management responsibility and formal documentation required. Closure plan needs to implement new controls or detail investigative tasks designed to reduce residual risk to a level acceptable to all stakeholders. Upgrade corporate procedures / instructions if required.	The mine closure plan should list quantitative completion criteria, including details on performance indicators, targets and thresholds. Monitoring at early stages is required, should be comprehensive and occur at a frequency able to rapidly detect if adaptive management is required.
High	This level of risk is not tolerable, senior management responsibility and formal documentation required. Mine closure plan needs to implement new controls or detail investigative tasks designed to reduce residual risk to a level acceptable to all stakeholders. Upgrade corporate procedures / instructions if required.	The mine closure plan should list quantitative completion criteria, including details on performance indicators, targets and thresholds. Monitoring at early stages is highly recommended, should be comprehensive and occur at a frequency able to rapidly detect if adaptive management is required.
Moderate	Management responsibility must be specified in documents, this level of risk is acceptable provided all possible efforts have been made to implement proposed controls. Assess adequateness of existing controls in conjunction with key stakeholders, upgrade corporate procedures / instructions if required.	The mine closure plan may include detailed or indicative completion criteria. Monitoring at early stages is recommended, should be comprehensive and occur at a frequency able to detect if adaptive management is required.
Low	This level of risk acceptable with standard management procedures / instructions that incorporate annual internal review.	Indicative criteria to be included in the mine closure plan, with further (quantitative) detail required in later versions. Some monitoring should be undertaken.
Very Low	Manage by routine procedures; accept risk.	Attribute should be mentioned in mine closure plan to inform indicative qualitative completion criteria. Attributes with risk rating equal to one (1) may be excluded from list of completion criteria.

Source: Doray Minerals Limited 2012

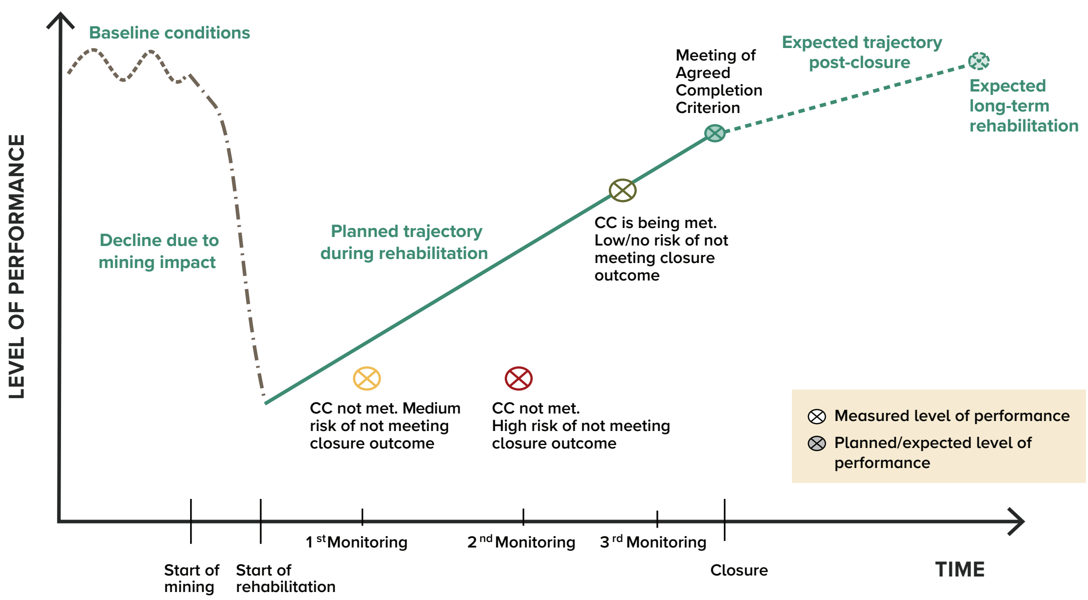
2.8 Component 5 – Completion criteria

COMPLETION CRITERIA: Agreed standards or levels of performance that indicate the success of rehabilitation and enable an operator to determine when its liability for an area can cease.

Once attributes have been selected and prioritised (following Step 4), a completion criterion may be defined by setting a target that will allow the fulfilment of closure objectives. Targets are informed by the reference value for the attribute and must be set to levels that makes them attainable for the particular site and, where appropriate, within a specified timeframe, recognising that the outcome must be supportive of the agreed PMLUs. At the same time, standards must be high enough to ensure that, once they are met, the risk of no-fulfilment of closure objectives is brought down to low or zero.

In early stages of mine closure planning, it is often not known what the attainable and necessary levels of performance will be at time of closure. Hence, information from reference sites (selected in Step 3) may provide an evidence-based indication of the adequate standards for each attribute. For instance, if the agreed PMLUs is to revert to previous land use, then standards should be set at similar levels to those in the baseline conditions. Importantly, standards present in natural ecosystems may take a long time to be reinstated post-disturbance however, decisions will need to be made that the ecosystem is developing towards or has developed to a satisfactory level. Therefore, where appropriate, completion criteria should be time-bound, meaning that targets must be associated to a certain point in time. Defining completion criteria in a time-bound manner is a useful tool given that the same targets at different points in time can reflect very different levels of performance. For example, a vegetation cover of 25% of the mean of the baseline site three years after seeding may be an indication that the vegetation closure objective is likely to be met. Conversely, 25% of the baseline vegetation cover 10 years post replanting most probably points at a failure to fulfil the closure objective. Understanding a systems trajectory and how the indicator is performing relative to this is important when evaluating monitoring data (Figure 2.3) (Adapted from Grant 2006).

However, the same performance level later in time (2nd monitoring round) constitutes a significant gap between the planned and measured level of performance and may trigger corrective rehabilitation actions. Risk levels associated with each of these points are discussed in Step 6. Setting targets to establish a trajectory in a specific region or site may initially be challenging, with rates of rehabilitation yet to be established. Confidence in appropriate targets over time will increase with monitoring and experience. It should be recognised that the gradient or shape of a trajectory line may also not be linear, with alternatives being a curved or step-wise progression depending of the type of completion criteria to be achieved or alternatively may change all together as more data becomes available. Thresholds are another option which may be incorporated (see Figure 5.14) to allow for some variability in monitoring values over time and to incorporate trigger points at which further investigation into rehabilitation progressions is warranted.



Source: Adapted from Grant (2006)

FIGURE 2.3 Example of a trajectory approach for the definition of completion criteria

Completion criteria being time-bound also means that certain criteria must be achieved at specific times (e.g. early in the LoM) in order to allow attainment of successive criteria. For instance, correct landform construction should be achieved in early rehabilitation stages, thus ensuring that landforms may support successful revegetation as a result of adequate water retention, slope stability, etc. Correct landform construction is particularly important for pit lakes, prior to filling, to ensure that the fundamentals for allowing the lake to develop along a desirable trajectory are established. Planning for all completion criteria needs to be completed early even though the completion of various criteria may be successional. The time-lines to meet each completion criteria should be determined based on the specific circumstances of every mine site.

Completion criteria will often be defined using numeric targets, especially for parameter-based attributes, such as plant density, slope or soil pH. Targets set should be informed by data derived from the reference(s) to ensure they are meaningful and achievable, with evidence included in the mine closure plan to demonstrate how the numerical values were derived. It is also possible to define completion criteria using task or outcome-based targets as, for example, in the case of qualitative attributes, such as vegetation resilience, heritage, access or safety. In some cases, both quantitative and task-based targets can be used, e.g. landform design and construction (see Table 2.11). Table 2.6 and Table 3.7 list quantitative as well as categorical/qualitative and process/task-based criteria.

TABLE 2.11 Examples of numeric and outcome-based completion criteria

Aspect	Attribute	Completion criteria
Flora and vegetation	Plant density	X plants per ha at Y years post start of rehabilitation.
Social	Access and safety	Access to be restricted through fencing and signage.
Mine waste and hazardous materials	Landform design and construction	Landform slope < X°. Landform to be constructed in compliance with design specifications.

Completion criteria should account for spatial variation of targets within the mine sites. For example, different domains or areas may present different characteristics that do not allow the same level of performance to be achieved throughout the site. Definition on completion criteria by domain will assist with progressive rehabilitation, while recognising 'patchiness' or 'heterogeneity' within an area whilst still contributing to the overarching closure objectives.

Another important consideration in the definition of completion criteria is the difference between 'lagging' and 'leading' indicators (See Chapter 3). Lagging indicators are those that can only be measured after many years into the rehabilitation process e.g. fauna community return. Hence, completion criteria based on lagging indicators may be difficult to achieve, given the time required to assess success. Conversely, leading indicators are those that can be measured at early stages of rehabilitation and provide an indication of future rehabilitation outcomes, such as soil nutrient levels or initial plant populations. A practical example can be found in Alcoa's bauxite mine sites in the jarrah forest, where rehabilitation success is assessed based on four key leading indicators: 9-months stocking rate of Eucalyptus species; 9-month density of legumes; 15-months species richness; and 15-months density of re-sprouter species. Leading indicators can also serve as 'proxies' whereby the attribute of interest is not directly measured, but instead an alternative feature is used in the definition of completion criteria. For instance, Alcoa uses seeding rates and legume plant density as leading/proxy indictors of soil nitrogen (see Section 5.6.3). The correlation between the leading indicator/proxy must be clearly articulated and backed up by data in the mine closure plan.

The setting of numeric values which represent the targets of the completion criterion should be informed by the reference value and appropriate for supporting the PMLU. When numerical targets are set, they are not necessarily equal to those in the reference. Informed targets are a part of the key principles of completion criteria. It is important that completion criteria are:

- Agreed;
- Evidence based;
- S.M.A.R.T.;
- Supportive of PMLUs; and
- Achievable given permanent changes to landforms, soils and hydrology.

Several approaches to the setting of the numerical values of targets in relation to the reference may be employed including:

1. The **same as the reference value** (e.g. pre-mining or analogue condition). This may be the ideal approach in many circumstances as it does not involve any subjective judgement but merely represents like for like. This should include an assessment of achievability given changes to landforms, soils and hydrology.
2. **Exceeding the reference** may be appropriate in cases where assessment is required at a point in time and subsequent performance is expected to decline after this assessment time. Tree species density may be one example if, for instance, 8 year old rehabilitation is compared against a mature forest reference.
3. Based on **understanding of risk**. Where risk and control effectiveness are well understood, as may occur for engineering parameters, understanding the acceptable level of risk to delivery of effective PMLUs, including safety elements, may provide objective values for completion criteria targets.
4. Based on **common practice precedent**. An industry-wide or regional standard may already be in place that has proven achievable and acceptable to stakeholders – either an absolute value or a proportion of a reference value.
5. Based on **demonstrated best practice precedent**. A local standard may already be demonstrated for a site or region that has proven achievable and acceptable to stakeholders.
6. Based on **precedent set by previous approvals**. Standards may have been set in previous agreements, specifically in Ministerial statements, and could be applied in equivalent settings.
7. Based on an agreed **proportion of the reference value that is demonstrated** to deliver the support for PMLU required. Research or monitoring may be required to make this case.
8. Based on an agreed proportion of the reference value that is accepted, forming a **likely best guess** or **rule of thumb** that is able to support the PMLU required.

Depending on the monitoring approach, and the level of assessment required, criteria may be expressed as being either higher or lower than a threshold value, within a stated range, or statistically not different from the target value (allowing some sites to lie above while others are below the target).

2.9 Component 6 – Monitoring

The main objective of monitoring in this framework is to assess whether the completion criteria have been fulfilled, or are likely to be so, as per the company's closure plan. For this purpose, monitoring should be linked directly to the completion criteria, allowing any site to be compared with its agreed reference. The second goal of monitoring is to track progress and, thus, it should be such that any site can be compared with itself over time. Existing guidelines (ANZMEC & MCA 2000; DMP & EPA 2015; ICMM 2008; LPSDP 2016d) provide further recommendations on how monitoring should be conducted, yet there is still a need for a clearer framework that will help define more accurate and effective monitoring programs (see interviews in Chapter 4).

Monitoring can be useful or required in a mine closure context for purposes other than assessing completion criteria (see section 3.7), but in this review only monitoring that is relevant to completion criteria assessment is considered.

Monitoring should be accurately defined and broken down into separate tasks. What is commonly referred to as monitoring, is comprised of three distinct steps:

- **Data monitoring:** gathering, analysis and interpretation of information;
- **Auditing and evaluation:** systematic review of monitoring information against agreed completion criteria; and
- **Corrective action:** redefinition of a) rehabilitation program, b) completion criteria or c) both.

Data monitoring consists of collection and interpretation of information that is necessary to assess the progress towards meeting completion criteria. Data monitoring should be targeted to those indicators that are used in the definition of completion criteria, excluding the need to collect redundant information. Information for the selected indicator needs to be available for the reference to allow auditing. It is important to acknowledge that not all attributes included in the MCP will need to be monitored to the same level of detail and with the same frequency. Hence, the risk-based attribute prioritisation approach (Section 2.7.2) allows the identification of which attributes should be closely monitored. For the purpose of planning of monitoring activities, Table 2.6 can be used as a guide by adding a column summarising indicators, methods and frequency of monitoring for each attribute. Examples of monitoring for completion criteria are provided in Table 2.12 and, in relation to project risk, in Table 3.11. It should be noted that columns in Table 2.12 follow the sequential process defined by the framework. The column 'Monitoring Plan' illustrates examples of proposed monitoring strategies, which often need to be outlined in early version of mine closure plans. As rehabilitation works advance, observable progress (or the lack thereof) should be documented, as exemplified in 'Monitoring results'. Subsequently, the column 'Auditing and Evaluation' illustrates the process whereby the observed level of rehabilitation is compared against the set targets to assess whether criteria have been met or are trending towards the agreed outcomes. Finally, 'Corrective Action' provides examples of the strategies that need to be implemented to meet completion criteria, based upon the monitoring, auditing and evaluation results. Usually, 'Monitoring results', 'Auditing and evaluation" and 'Corrective action' are recorded as part of companies' internal management processes, but not necessarily reported in Mine Closure Plans – unless requested by the regulator.

Auditing is the process whereby the site's level of rehabilitation performance – as reflected in the monitoring data – is compared with the standards agreed in the completion criteria. The difference between the actual and planned performance levels will indicate whether completion criteria are being met and, thus, whether the site is on the right 'trajectory' towards fulfilling closure objectives. Auditing is necessarily time-bound, given that a level of performance can indicate either success or failure, depending on how much time has elapsed since start of rehabilitation or how much time is left before the planned closure date (see Component 5). The risk of each attribute preventing the fulfilment of closure objectives should be re-evaluated following each monitoring round. The process will follow the same approach as described in Component 4, where likelihood and consequences are assessed to determine risk of non-compliance.

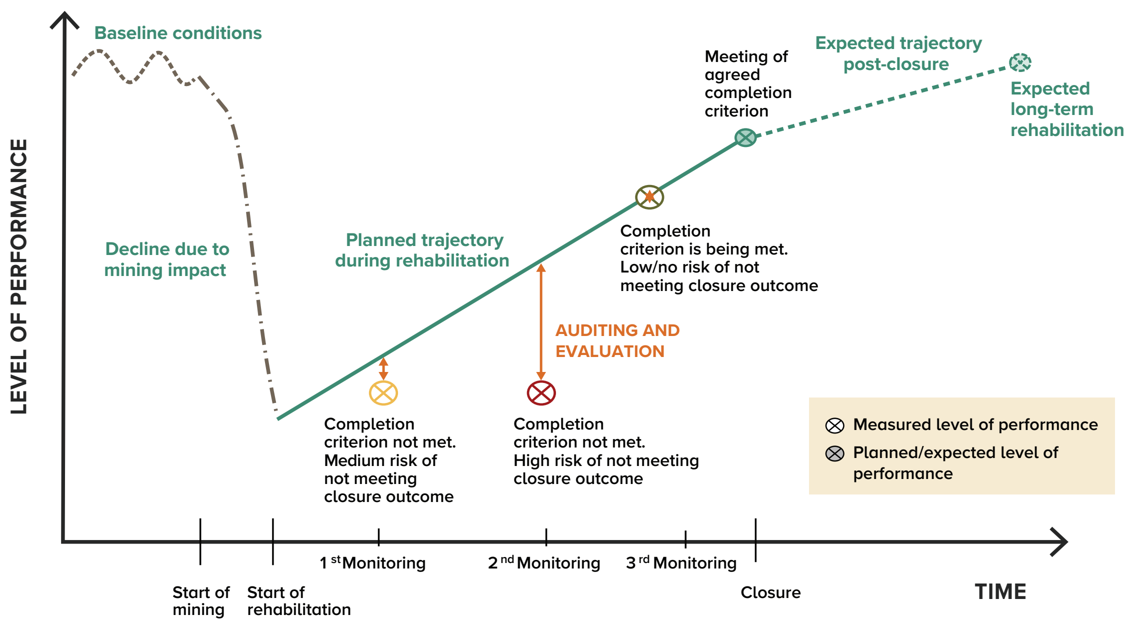


FIGURE 2.4 Auditing and evaluation along the planned rehabilitation trajectory

Finally, corrective actions are the necessary processes to be undertaken that will ensure closure objectives are met, in those cases where a significant risk of non-compliance has been identified. When auditing identifies that there is a risk of not meeting completion criteria, this should trigger investigations into causes of such failure, including questioning whether:

- Rehabilitation practices are not effective and need to be modified including potentially new rehabilitation techniques previously unavailable or considered inappropriate;
- Completion criteria are unachievable and need to be modified; or
- Both rehabilitation practices and completion criteria need to be modified.

While rehabilitation programs should be science-based and thoroughly planned, it is possible that practices are poorly implemented or that the proposed methods are not suitable for the specific mine site. In such cases, an expert assessment should be conducted to redefine a new set of practices aimed at improving the site's rehabilitation performance levels (see example in Figure 2.5).

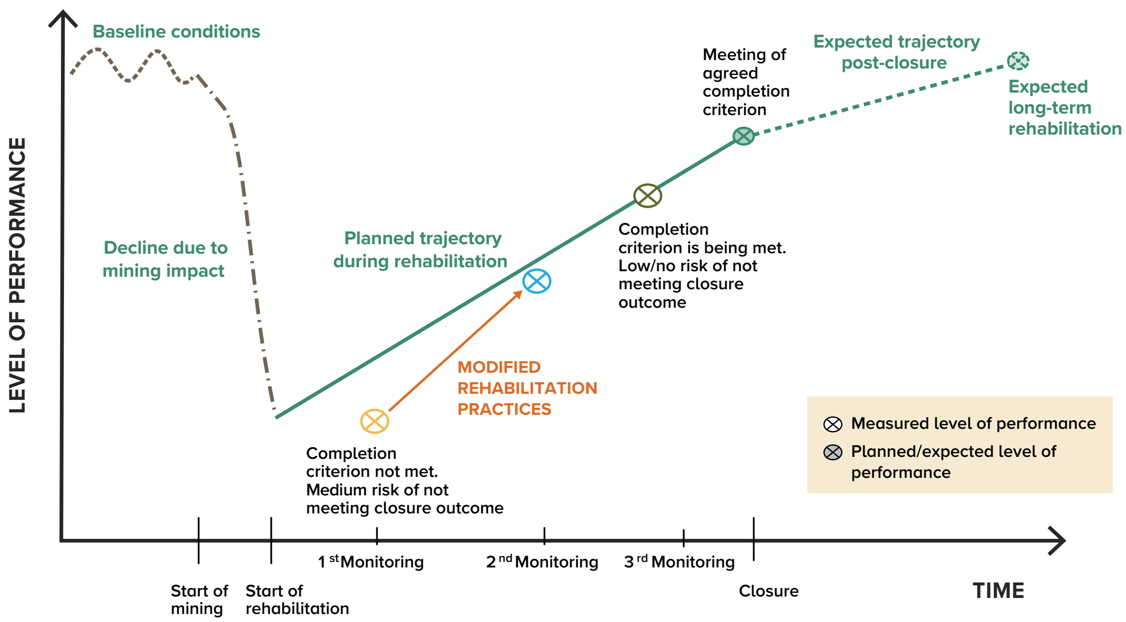


FIGURE 2.5 Corrective Action: Improved Rehabilitation Practices

It is also possible that, as rehabilitation progresses and more monitoring data becomes available, completion criteria initially agreed upon are later understood to be unachievable. For example, climate change impacts may be hard to predict in 20–30 years' time, which means that criteria set using today's knowledge may overestimate what will be feasible at the time of closure. Under these scenarios, companies need to investigate the factors that have influenced failure to meet the completion criteria. A thorough review of available all evidence (data) and science would be required to be provided to the regulators in order to inform the new standards for the redefinition of completion criteria (Figure 2.6).

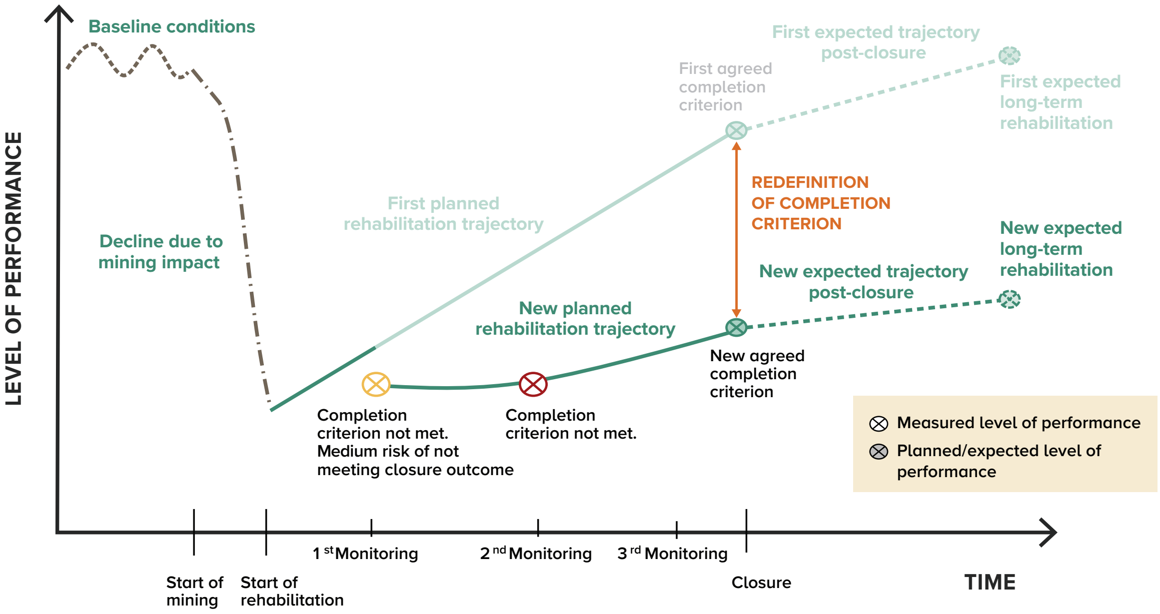


FIGURE 2.6 Corrective action: Redefinition of completion criteria

A third scenario is the situation where completion criteria become unachievable and need to be redefined, but at the same time, improved rehabilitation practices are also required to increase the level of performance of rehabilitation (Figure 2.7). An example may be a mine site where an extreme weather event alters the planned trajectory of rehabilitation. As one interviewee (Chapter 4) described, based on a real experience in the Pilbara region, planted seeds were ripped away by a severe storm which impacted the planned rehabilitation progress. In such circumstances, the time-specified rehabilitation trajectory may be adjusted, while reseeding and careful management of sprouting plants would be also required.

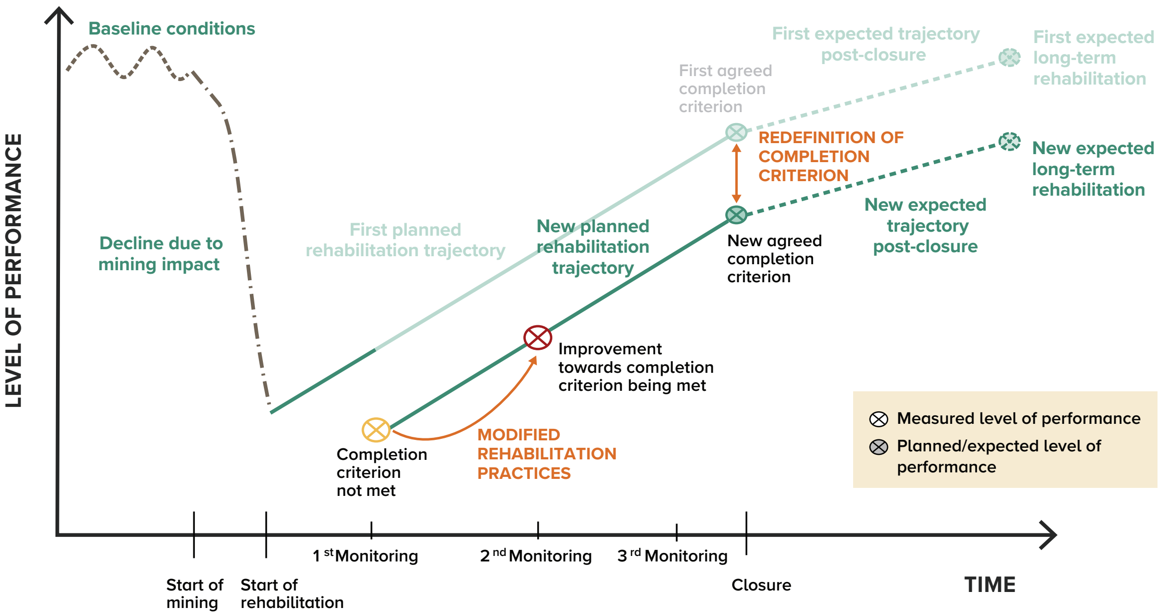


FIGURE 2.7 Corrective action: Modified rehabilitation practices and redefinition of completion criteria

Some completion criteria, such as recovery of groundwater levels or vegetation cover, may be associated with an expected trajectory. By contrast, other criteria, such as the removal of non-transferrable infrastructure, do not follow a trend but are the result of an action undertaken at a certain point in time. It is also important to note that trajectories for certain completion criteria may be more easily defined in environments were weather patterns are predictable and rehabilitation trends are well understood, such as the result of research and data records dating back many years. By contrast, in landscapes suffering from erratic rainfall and periodic droughts, it may be harder to predict the timeframes for certain completion criteria to be met (e.g. vegetation). In such cases, it is advised that mining proponents keep a time-bound record of rehabilitation works that precede plant growth e.g. adequate landform design and construction, erosion management, seeding or planting and pest management. Such records may serve as supporting evidence to the regulator that adequate practices are carried out – albeit with an uncertain outcome.

As discussed above, when completion criteria are not being met or rehabilitation is not trending towards the agreed target, mining proponents should investigate the factors that have influenced such failures. Thus, progress towards meeting each completion criterion should be documented and regularly updated based on the data assimilated from the ongoing monitoring. An assessment of the progress towards whether the completion criteria has been met, is on a trajectory to be met or requires remedial action is required to inform management on projections for resource allocation.

2.9.1 Change management

Inevitably over the life of mine as market conditions, environmental conditions, company structures and government regulations change there may be a requirement for industry to adapt their site-based closure planning. The variables that may instigate change and the implications for this change towards closure can be significant and companies need to be prepared to adapt. Examples of change that may be required include the agreed upon PMLU, completion criteria and/or monitoring techniques and the reiterative process in the framework (Figure 2.2) highlights that adapting to change is possible. If change to the PMLU is required then it may require a revised set of completion criteria to be developed based on a new risk-based attribute prioritisation. However, simpler changes such as the incorporation of new monitoring methodologies may only require an explanatory document to outline how the monitoring results between old and new technologies will be aligned and how progression towards trajectory will still be able to be tracked. Regardless of the level of change, as change occurs, making decisions based on well-documented science and keeping a clear, transparent record of agreements/negotiations with stakeholders will help minimise discrepancies across time and staff and facilitate the update of closure targets.

2.9.2 Learnings and innovation

The quality of rehabilitation in Western Australia has seen significant improvement over recent decades and many companies in the resources sector have worked with research partners and leading consultants to innovate and improve environmental performance and health and safety management processes (Commonwealth of Australia 2018). Examples of the substantial benefits obtained when industry has formed long-term relationships and worked with external experts are evident throughout the state and include large-scale long-term investments (Erickson *et al.* 2016, Stevens *et al.* 2016) as well as smaller-scale projects undertaken in a single or few seasons (Grant *et al.* 1996, Barritt *et al.* 2016, Cross *et al.* 2018a). The demonstrated commitment of industry to improve performance is critical in developing and maintaining a positive social licence to operate (Commonwealth of Australia 2018).

Whether industry chooses to engage with researchers and/or leading consultants or not, the importance of detailed documentation of rehabilitation methodologies, site conditions and performance that are regularly updated, allows the continual improvement of outcomes and efficiencies of resources. It is important that the monitoring data collected across all aspects, attributes and completion criteria are reviewed regularly and procedures updated to ensure site-based activities are in line with leading practice.

TABLE 2.12 Example of completion criteria, monitoring and assessment based on risk-based attributes

Step 1	Step 2		Step 3	Step 4				
PMLUs	Aspects and closure objectives		Reference	Attribute	Risk-based attribute prioritisation			
	Aspect	Closure objectives			Description of risk	Likelihood	Consequence	Risk level
1.1.0 Nature conservation	Ecosystem function and sustainability	The rehabilitated ecosystem is self-sustaining and is indicative of baseline conditions.	Analogue site	Plant species reproduction and recruitment	Established vegetation communities at restoration sites with low fecundity and poor recruitment.	3	4	H12
	Flora and Vegetation	The rehabilitated area has a vegetation community that is commensurate with the baseline conditions.	Baseline conditions	Species richness and cover	Established vegetation community richness and/or cover is inadequate.	3	3	M9
3.2.4 Grazing modified pastures, pasture legume/grass mixture	Social	The visual impact of the rehabilitated mine site compatible with surrounding landscape and acceptable to stakeholders.	Analogue site	Aesthetics (visual amenity)	The post-mining topography does not adequately integrate with the surrounding natural topography. Breach of approval commitments. Visual amenity impact. Local complaints.	2	4	M7
5.2.3. Intensive animal production, poultry farm	Mine Waste and Hazardous Materials	All redundant post-mining and mineral processing infrastructure to be salvaged and disposed of appropriately. Items with beneficial uses post-operations may be left in situ following negotiations with post-closure land users (roads, sheds etc.). Formal transfer of liability to the post-mining landholder has been obtained for any retained infrastructure.	Conceptual Model	Infrastructure	Infrastructure buildings transferred to land owner is not safe with risk of fall from heights, electrocution.	1	4	M5

Example

Note: Examples are not exhaustive in nature and may not be relevant or applicable to sites at all geographical regions. Multiple attributes may be required to demonstrate that a completion criterion has been met. Risk-based attribute prioritisation is based on an initial risk rating; mitigation strategies to reduce risk with a revised risk level could be added at step four. Further, the example layout is time sequential with monitoring occurring at a time occurring post completion criteria development. Additional columns could be added to track monitoring success/progress over several sequential monitoring periods.

Table 2.12 continues following page...

TABLE 2.12 Example of completion criteria, monitoring and assessment based on risk-based attributes

Step 1	Step 5	
PMLUs	**Completion criteria**	**Rehabilitation practices**
1.1.0 Nature conservation	The number of native flora species recorded as naturally recruited juveniles is ±50% that recorded in reference sites, with ±10% surviving to maturity. ±50% of the native species recorded are observed to flower and fruit on the rehabilitation area. Species demonstrated to be actively recruiting represent all strata present in the baseline conditions. The rehabilitated area has been assessed to have the properties of a self-sustaining system by a qualified expert.	Rehabilitation in accordance with MCP. Monitoring of restoration and reference sites for plant fecundity and recruitment rates.
	The vegetation community on the rehabilitation site will have a species richness no less than the 70% of the vegetation recorded in baseline surveys. Total native perennial vegetation cover to be ≥ 20%.	Rehabilitation in accordance with MCP. Monitoring of restoration and reference sites for species richness and cover.
3.2.4 Grazing modified pastures, pasture legume/grass mixture	The post-mining profile will be integrated into the surrounding undisturbed landscape, continuing the gently sloped undulating plain. No slopes greater the 15% will remain at closure. The post-mined land surface will be within ± 1.0 m of the approved rehabilitation design for 95% of the disturbance area.	Engage with stakeholders on final landform designs and obtain endorsement from key stakeholders. Conceptual landform design to reflect natural topographic features.
5.2.3. Intensive animal production, poultry farm	Retained infrastructure will be left in a safe condition and transferred to a legally responsible entity. Retained buildings or infrastructure have been issued the necessary safety compliance certificates or permits. Open pits will be left in accordance with the guidelines on "Safety Bund Walls and Abandoned Open Pits" (DIR, 1997).	Ensure building infrastructure complies with safety standards. Building certificates obtained for structures retained. Electrical safety certificates obtained for retained electrical infrastructure. Additional safety certificates obtained where necessary.

Note: Examples are not exhaustive in nature and may not be relevant or applicable to sites at all geographical regions. Multiple attributes may be required to demonstrate that a completion criterion has been met. Risk-based attribute prioritisation is based on an initial risk rating; mitigation strategies to reduce risk with a revised risk level could be added at step four. Further, the example layout is time sequential with monitoring occurring at a time occurring post completion criteria development. Additional columns could be added to track monitoring success/progress over several sequential monitoring periods.

Table 2.12 continues following page...

TABLE 2.12 Example of completion criteria, monitoring and assessment based on risk-based attributes

Step 1	Step 6			
PMLUs	Monitoring			
	Monitoring plan	Monitoring results during rehabilitation	Auditing and Evaluation	Corrective action
1.1.0 Nature conservation	Qualitative assessment of vegetation communities and health including richness, cover, flowering, fruiting, soil seed bank audit and recruitment at 1, 2, 3 and 5 years. Monitoring of plant health (ecophysiology) over drought period in restoration and at reference. Monitor for structurally dominant species reaching an age sufficient to recover post-fire.	Monitoring quadrats at 2 years after rehabilitation practices: 55% of native perennial species have reached sexual maturity and fecundity rates match the same species from the reference site (±10%). Evidence of grazing recorded for 15% of species. Mean rates of gas exchange (ecophysiological health) of indicator species for plants of similar ages was 30% lower in the rehabilitation site when compared to plants from the reference sites. Soil seed bank viability has reached 30% of that observed at reference.	Criteria not achieved but progressing along a trajectory to reach targets. Impacts of grazing likely to be affecting percentage of plants reaching sexual maturity. Plants in rehabilitation site showing higher levels of stress than at reference.	Installation of fencing to reduce grazing pressure and compaction. Monitor again in 12 months and, if necessary, implement additional remedial actions to improve measures of ecosystem function and sustainability. Review rehabilitation plan and consider irrigation during early plant establishment.
		Monitoring quadrats show at 2 years after rehabilitation practices, species richness is 35% of baseline conditions. Total native perennial cover ranges for 5-15%.	Criteria not achieved. Species richness is low and remedial action is required. Cover is progressing along a trajectory to reach targets.	Options to increase species diversity to be investigated including re-broadcasting of seed and planting of seedlings. Consider irrigation following seeding/planting during early plant establishment to facilitate survival.
3.2.4 Grazing modified pastures, pasture legume/grass mixture	Visual impact evaluation, records of stakeholder endorsement and landform construction report.	Post-mining landform restoration is complete. Rehabilitation land contours integrate with the surrounding areas with the majority conforming with completion criteria targets. Expert review of landscape identified minor instability and erosion risk on south facing slope in Domain 3. The rehabilitated agricultural land is visually compatible with the surrounding landscape (see figures).	Criteria has been achieved for Domain 4 and with minor remedial actions required in Domain 3. Supporting documentation, reports and signed agreements filed in document management system (link to file)	Minor corrective earthworks required in Domain 3, south facing slope to stabilise landform.
5.2.3. Intensive animal production, poultry farm	Inspections of retained features prior to handover. Safety and compliance certificates for retained infrastructure. Signed asset transfer agreement in place prior to transfer of legal responsibility. Review against Decommissioning Plans.	Building and electrical certificates for Industrial shed (Domain 1) obtained March 2018. Written landowner acceptance of retained infrastructure. Certifications filed and located here.	Relevant permits and certificates obtained. Transfer of liabilities completed.	None required.

Note: Examples are not exhaustive in nature and may not be relevant or applicable to sites at all geographical regions. Multiple attributes may be required to demonstrate that a completion criterion has been met. Risk-based attribute prioritisation is based on an initial risk rating; mitigation strategies to reduce risk with a revised risk level could be added at step four. Further, the example layout is time sequential with monitoring occurring at a time occurring post completion criteria development. Additional columns could be added to track monitoring success/progress over several sequential monitoring periods.

2 CHAPTER

Photo courtesy: Mike Young

3 Background, principles and context for risk-based completion criteria and monitoring

This section includes a review of current guidance, policy and scientific literature relating to completion criteria and associated monitoring. It focusses particularly on criteria and attributes relating directly, or indirectly, to biological elements in rehabilitation sites. It also considers methodologies for the selection of post-mined land uses (PMLUs), the consideration of offsets and application of risk assessment in identifying closure risk and in directing and prioritising rehabilitation effort. When discussing specific aspects and attributes, the study focusses on biophysical and environmental elements, but indicates to other elements where appropriate. This focus reflects the scope of the report, but also that most mine closure plans include environmental requirements. PMLUs that do not include environmental objectives will require consideration of other aspects and monitoring approaches (e.g. social or economic metrics). Nonetheless, the principals for completion criteria development, discussion of risk and approaches to selecting PMLUs should be relevant to all mines.

3.1 Guidelines and principles for establishing completion criteria

The importance of completion criteria in the mining life-cycle are well recognised in numerous international and national handbooks and guidelines for mine closure planning. While there is no international or national standard for the development of completion criteria (Blommerde *et al.* 2015), more than 30 documents with guidance for the establishment of completion criteria – from jurisdictions across Australia (state and federal), Canada (provincial and federal), Peru, Chile, South Africa, Finland, Asia Pacific Economic Cooperation (APEC) and states within the United States of America – were identified. The most relevant of these are reviewed below.

Documents from NSW (TIRE 2013) and Queensland (DEHP 2014) provide information specific to the mine rehabilitation and closure requirements of their jurisdictions, with the most detailed guidance on objectives and criteria for closure being provided by DEHP (2014). Rather than provide substantial detailed information on criteria development, the NSW guidance relies substantially on the Strategic Framework for Mine Closure (ANZMEC & MCA 2000) as a recommended source.

The nationally focussed Australia and New Zealand Minerals and Energy Council/ Minerals Council of Australia Strategic Framework (ANZMEC & MCA 2000) is an industry document, which promotes establishment of completion criteria that are developed and agreed with stakeholders. It states that, where possible, completion criteria should be quantitative and capable of objective verification, and identifies the importance of developing performance indicators to measure progress in meeting the completion criteria – which is distinct from, but supplementary to, monitoring to assess completion criteria.

The Leading Practice Sustainable Development Program (LPSDP) for the mining industry handbook series includes handbooks devoted to mine closure (LPSDP 2016d), mine rehabilitation (LPSDP 2016e), biodiversity management (LPSDP 2016a) and evaluating performance: monitoring and auditing (LPSDP 2016b), among others. This excellent series, which aims to encourage best practice sustainable mining both in Australia and overseas, was developed by Australian Government Department of Industry, Innovation and Science in partnership with the Department of Foreign Affairs and Trade and input from diverse contributors (DIIS 2018). The first handbook (Mine Closure; LPSDP 2006d) specifically promotes monitoring against closure objectives and criteria, with detailed guidance on objectives, principles and nature of criteria. It promotes a phased approach for criteria (development and mining; planning and earthworks; vegetation establishment; monitoring and closure). The Mine Rehabilitation handbook (LPSDP 2016e) promotes SMART (Specific Measurable Achievable Relevant and Time-bound) targets and objectives, that criteria are developed with stakeholders and recommends comparison with analogues. The handbook on monitoring (LPSDP 2016b) makes a strong link between criteria and monitoring. It provides examples of typical elements of completion criteria for landforms, water and biodiversity.

Internationally, the Canadian federal government provides a detailed overview of recommended environment management practices for all stages of the mining life cycle, including rehabilitation and closure in an 'Environmental Code of Practice for Metal Mines' (Environment Canada 2009). This overview publication does not address completion criteria and is limited to recommending post-closure monitoring to ensure that closure and rehabilitation measures are functioning as designed, and to demonstrate compliance with the targeted end land use. Importantly, the document does give a substantial list of sources of additional information, most from Canadian provinces but including a range of Australian publications (federal and state).

An example of a detailed consideration of criteria for closure in a Canadian jurisdiction is the guidelines for closure and reclamation in the Northwest Territories (AANDC 2013). Although the dominant environmental factors considered in those guidelines contrast strongly with those in Western Australia, a useful detailed approach is provided to establish a closure goal which must embody four closure principles: physical stability, chemical stability, no long-term active care and future use (including aesthetics and values). These closure principles guide the selection of closure objectives and criteria for mine closure (AANDC 2013).

The Canada Mining Innovation Council (CMIC) is currently undertaking a program to develop a standardised, performance-based framework for mine closure relinquishment (CMIC 2015). In order to reflect the diversity of environments, commodities and mining operations, the initiative has not been directed at defining detailed criteria with standards, but focused on standardising 'categories' (equating to 'aspects' in this review) and criteria ('attributes', see Table 1.1). Similar to the current project, the CMIC's framework was to be developed in consultation with stakeholders in order to reach a broad consensus regarding the acceptable conditions for mine closure and subsequent site relinquishment (Holmes *et al.* 2015).

The remaining international examples of guidance on requirements for mine closure that were reviewed but not listed in Table 3.1 consistently identified objectives and criteria as being required, but there was little detailed guidance on establishing them.

Photo courtesy: BHP

TABLE 3.1 Published guidelines relating to mine closure and or completion criteria

Region	Document title	Reference	Details
INTERNATIONAL			
Global	Planning for Integrated Mine Closure: Toolkit	ICMM 2008	Encourages development of closure goals (equating to criteria with a measurable standard) and monitoring to demonstrate progression towards them and their achievement. Includes examples of aspects to consider and examples of related goals for some of those. Also includes intermediate (partial) goals to mark progress.
Global	International standards for the practice of ecological restoration – including principles and key concepts	McDonald *et al.* 2016	As for Society for Ecological Restoration Australasia (SERA) (SERA 2017) below, sets out framework of 'goals' and 'objectives' (criteria/standards), together with examples of specific objectives (criteria) for soils, and biological elements.
APEC	Mine Closure Checklist for Governments	APEC (2018)	A checklist for governments, not industry. Promotes consideration of the proposed post-closure land use for the landform, including closure objectives and closure criteria. Includes reference to Australian Mine Closure Handbook (LPSDP 2016d) and guidelines from Northwest Territories (AANDC 2013).
Finland	Mine Closure Handbook	Heikkinen *et al.* 2008	General guidance and examples for developing objectives and performance criteria in relation to environmental quality.
Canada	Environmental Code of Practice for Metal Mines	Environment Canada (2009)	Detailed summary of recommended environment management practices for all stage of the mining life cycle, including rehabilitation and closure. Contains extensive list of additional sources of information, including those related to mine rehabilitation and closure.
Canada – Northwest Territories	Guidelines for the Closure and Reclamation of Advanced Mineral Exploration and Mine Sites in the Northwest Territories	AANDC (2013)	Clear and detailed guidance on expectations and framework. Strongly focused on water as the key aspect/environmental factor. The closure goal is supported by closure principles which guide selection of clear and measurable closure objectives for all project components. Closure criteria can be site specific or adopted from provincial/territorial/federal standards and can be narrative statements or numerical values.
South Africa	Regulations pertaining to the financial provision for prospecting, exploration, mining or production operations	Department of Environmental Affairs (DEA) (2015)	Indicates a clear requirement for closure plans to be measurable and auditable, and to provide a vision, objectives, targets and criteria for final rehabilitation, decommissioning and closure. Does not contain guidance on criteria development.

Table 3.1 continues following page...

TABLE 3.1 Published guidelines relating to mine closure and or completion criteria

Region	Document title	Reference	Details
NATIONAL			
Australia and New Zealand	Strategic Framework for Mine Closure	ANZMEC & MCA (2000)	Promotes establishment of completion criteria that are developed and agreed with stakeholders and, where possible should be quantitative and capable of objective verification. Identifies the importance of developing performance indicators to measure progress in meeting the completion criteria, indicating appropriate trends or enabling early intervention where required.
Australia	Mine closure	LPSDP (2016d)	Promotes monitoring and reporting against agreed closure objectives and closure criteria. Relatively detailed guidance on objectives, principles and nature of criteria. Discusses a phased approach for criteria (development and mining; planning and earthworks; vegetation establishment; monitoring and closure).
Australia	Mine rehabilitation	LPSDP (2016e)	Promotes SMART targets and objectives, with success criteria that have been developed with stakeholders. Recommends comparison with analogues, not to replicate them but to inform in relation to composition, structure and function.
Australia	Biodiversity management	LPSDP (2016a)	Touches lightly on objectives and criteria with respect to biodiversity. Identifies that direct measures of abundance for fauna are lagging indicators.
Australia	Evaluating performance: monitoring and auditing	LPSDP (2016b)	Provides clear guidance on the nature and role of criteria, including the relationship of criteria to monitoring. Links strongly to related LPSDP handbooks. Gives examples of typical elements of completion criteria, for landforms, water, biodiversity, though without discussing matching of specific criteria with different stages of rehabilitation process.
Australia	National standards for the practice of ecological restoration in Australia	SERA (2017)	Set out framework of 'goals' and 'objectives' (criteria/standards), together with examples of specific objectives (criteria) for soils, and biological elements.
STATE			
Western Australia	Guidance for the Assessment of Environmental Factors	EPA (2006)	Aims to encourage best practice in setting appropriate and effective objectives for rehabilitation and assessing subsequent outcomes and promotes more effective monitoring and auditing of outcomes.
Western Australia	Guidelines for Preparing Mine Closure Plans	DMP & EPA (2015)	Specific guidance on identifying land use, closure objectives, completion criteria. Refers to ANZMEC & MCA (2000) for additional information. Includes example of tabular framework for factor, objective, criteria and measurement tools.
Western Australia	Guidelines for Mining Proposals in Western Australia	DMP (2016)	Identifies the need for performance criteria for each environmental outcome. Closure outcomes, together with related completion criteria, should be outlined in a Mine Closure Plan (MCP). Principles and purpose of monitoring for each criterion is discussed. Includes example tabular framework for factor, objective, risk, outcomes, criteria and monitoring.
NSW	Mining Operations Plan (MOP) Guidelines	TIRE (2013)	Clear expectation to provide objective criteria to establish whether rehabilitation objectives have been met; and have outcomes which are demonstrably achievable through experience in comparable situations or through site trials/research. General guidance and examples on where criteria should be directed, but not on their development or structure.
Queensland	Rehabilitation requirements for mining resource activities	DEHP (2014)	Sets out clear hierarchy for rehabilitation goals, objectives, indicators and criteria. Detailed example of objectives, indicators and criteria.

3.2 Establishing completion criteria in Western Australia

The most relevant and detailed sources of publicly available guidance for establishing completion criteria in Western Australia are those from the Western Australian Environment Protection Authority (EPA 2006), Western Australian Department of Mining and Petroleum (DMP, now Department of Mines, Industry Regulation and Safety; DMIRS) (DMP & EPA 2015) and the Australian Government's Leading Practice Sustainable Development Program (LPSDP 2016c,d). Despite their similar aims, these vary in focus and formulations of completion criteria. EPA (2006) focusses on outcomes while DMP & EPA (2015) is process oriented. While the two guiding documents demonstrate disparity, completion criteria can be developed that conform to both sets of guiding principles (Table 3.2).

TABLE 3.2 Principles for the Development of completion criteria in Western Australia

Guidance for the Assessment of Environmental Factors: Rehabilitation of Terrestrial Ecosystems (EPA 2006)	Guidelines for Preparing Mine Closure Plans' (DMP & EPA 2015)
• Allow success to be measured within realistic timeframes, • Be sufficiently precise to allow outcomes to be effectively audited, but are also flexible when required, • Be based on sound scientific principles, • Acknowledge the consequences of permanent changes to landforms, soils and hydrology, • Be attainable in realistic timeframes, and • Ensure rehabilitation objectives have been met.	• Be developed in consultation with DMP and EPA • Be appropriate to the developmental status of the project • Follow the S.M.A.R.T principle – being: **Specific** enough to reflect a unique set of environmental, social and economic circumstances; **Measurable** to demonstrate that rehabilitation is trending towards analogue indices; **Achievable** or realistic so that the criteria being measured are attainable; **Relevant** to the objectives that are being measured and the risks being managed and flexible enough to adapt to changing circumstances without compromising objectives; and **Time-bound** so that the criteria can be monitored over an appropriate time frame to ensure the results are robust for ultimate relinquishment

These guidance publications (EPA 2006, DMP & EPA 2015) set out objectives for rehabilitation and closure (Table 3.3), which provide context for development of completion criteria. Most examples from industry of frameworks for objectives and criteria for mine rehabilitation and closure in Western Australia are based on the core structure proposed in the WA Guidelines for Preparing Mine Closure Plans (DMP & EPA 2015). Criteria are typically listed in terms of the various aspects (see Table 3.6) that together represent all elements to be considered in closure.

TABLE 3.3 Guidance for setting objectives for rehabilitation and closure in Western Australia

EPA (2006)	DMP & EPA (2015)
• Safe, stable and resilient landforms and soils; • Appropriate hydrology; • Providing visual amenity, retaining heritage values and suitable for agreed land uses; • Resilient and self-sustaining vegetation comprised of local provenance species; • Reaching agreed numeric targets for vegetation recovery; and • Comprising habitats capable of supporting all types of biodiversity.	• Physically safe to humans and animals; • Geotechnically stable; • Geochemically non-polluting/non-contaminating; and • Capable of sustaining an agreed post-mining land use.

Many Western Australia industry examples of completion criteria incorporate the additional dimension of sequential mine closure phases, with some criteria specific to each phase (Table 3 4). Typically, these phases segregate into planning/design, rehabilitation execution, and vegetation establishment and development. This reflects the reality that the physical elements of rehabilitation landforms are necessarily planned and constructed before biological components can be established. The structure of a progressive assessment sequence aims to eliminate re-work at later stages of ecosystem development. For example, the topography and soil profile of a rehabilitated site is best confirmed immediately following earthworks, when machinery is on site and access remains open. By contrast, rectification of landforms after several years of ecosystem development is inefficient, and risks disturbing the established ecosystem. An additional consideration in relation to ecosystem development is that different criteria may be appropriate at different phases. Successful rehabilitation is likely to follow a successional pattern which can be used to inform appropriate timeframes to apply to individual criteria or performance indicator targets.

TABLE 3.4 Industry examples of sequential phases used in completion criteria frameworks

Alcoa (2015)	Roy Hill Iron Ore (2018)	WA Oil Barrow Island (Stantec 2015)	Newmont Boddington Gold (Newmont 2012)	Mt Keith Nickel Mine (Stantec 2017)
Planning	Decommissioning	Earthworks and primary rehabilitation	Planning and landform construction	Pre-execution
Rehabilitation earthworks	Primary rehabilitation works		Surface preparation and vegetation establishment	Execution
Early establishment (0 to 5 years)	Early establishment	Early establishment		Post-execution
Vegetation 12 years and older	Relinquishment	Mature rehabilitation	Monitoring, remediation and relinquishment	

3.3 Risk assessments of rehabilitation and closure outcomes

3.3.1 Risk management

Risk management is an integral part of closure, decommissioning, rehabilitation and post-closure monitoring. When implemented effectively, it can enable an operation or project to identify risks and develop controls to achieve sustainable mine closure and relinquishment. Risks associated with the closure and post-closure phases in the mine life cycle cover both economic and non-economic consequences. These risks are long-term, and the expectations of the local community, government, landowners, neighbouring property owners and non-government organisations (NGOs) need to be considered (LPSDP 2016g).

The standard AS/NZS ISO 31000: 2018 Risk management – Guidelines (ISO 2018) provides a set of principles, a framework and a process for managing risk which can be used by any organisation regardless of its size, activity or sector. Organisations using it this framework can compare their risk management practices with an internationally recognised benchmark, providing sound principles for effective management and corporate governance.

Risk management frameworks encompass the identification, analysis, evaluation and treatment of risks. Historically, risk management approaches have focused on the technical aspects of risk management where contemporary risk approaches as described in ISO 31000:2018 Risk management—Guidelines now place more emphasis on communication at each stage of risk management.

Reflective of the importance of risk management during rehabilitation and closure is the level of current guidance on environmental risk assessments, which includes: the LPSDP – Risk Management (LPSDP 2016g) and Mine Closure (LPSDP 2016d) handbooks; the Guideline for Mining Proposals in Western Australia (DMP 2016) and Guidelines for Preparing Mine Closure Plans (DMP & EPA 2015), together with similar documents from Queensland (DEHP 2014) and NSW (TIRE 2013). All of these guidance documents advise on the assessment of environmental risk. DMIRS (2018) noted, however, that only a limited number of assessments incorporate the 'consequence' category, the environmental sensitivity of the area in which the activity is taking place.

3.3.2 Risk assessment

The AS/NZS ISO 31000: 2018 guidelines also outline the need to establish the context when conducting a risk assessment and recommends that the questions posed during the assessment are focused towards the purpose for which the assessment outcomes will be used. This includes defining how the results of the risk assessment will be used and assists in selecting the right risk assessment tool, level of effort and team for the assessment.

In South Africa, the Department of Environmental Affairs (2015) Regulations to the *Mining Act (1998)* (Appendix V) contain guidance on preparing an environmental risk assessment report, which specifically outlines the objective of the environmental risk assessment report, as follows:

- Ensure timely risk reduction through appropriate interventions;
- Identify and quantify the potential latent environmental risks related to post closure;
- Detail the approach to managing the risks;
- Quantify the potential liabilities associated with the management of the risks; and
- Outline monitoring, auditing and reporting requirements.

Leading risk management practitioners have recently shifted their focus from risk assessment to control management. This has significantly improved outcomes from the risk management process and reduced the potential for unplanned or unwanted events and outcomes (LPSDP 2016g). One method of incorporating risk planning into closure planning is to develop a risk register that incorporates the control measures to mitigate the risks (LPSDP 2016d).

Photo courtesy: BHP

3.3.3 Types of risk and considerations

Mining companies regularly conduct risk assessments that focus on health, safety, environment and financial risk. The latter includes corporate risks, such as company reputation damage from an environmental incident. From a completion criteria perspective, it is important for all stakeholders to consider the risks associated with different completion objectives, both for the construction of the completion criteria, but also for their associated monitoring approaches. The biological complexity of rehabilitation projects, the extent that these can be managed, challenges of the environment in which they occur, presence or absence of proven capability and knowledge for rehabilitation in that system, including its availability to the proponent, together with economic, political, social, timeframe or organisational factors all contribute to the risk of rehabilitation failure or success.

Technical deficiencies, such as; lack of investment in research driven improvement; lack of understanding of environmental impediments and failure to integrate rehabilitation and closure planning into the 'life of mine' planning can result in financial risk. Financial liability is a key driver for companies in identifying their biggest relinquishment risk, and where their closure efforts may be prioritised. This has been reflected by the Queensland Department of Environment and Heritage Protection (DEHP 2014), which presents a calculation of cost of the residual risk of a rehabilitation strategy. This cost influences a 'residual risk payment' at relinquishment, which reflects the nature and scale of the risk that the Government is accepting.

An important consideration during risk assessments is that potential changes to regulations may lead to unacceptable performance outcomes, due to increasing requirements at closure. Mechanisms to reduce this risk include keeping up-to-date with new and changing regulatory requirements and ensuring rehabilitation operations are consistent with scientific best practice. Consultation with regulators enables companies to mitigate the risk associated with attaining an unacceptable rehabilitation outcome, whilst internal benchmarking exercises and development of specific and measurable completion criteria that are agreed with stakeholders can be utilised to verify the rehabilitation practices that are applied.

Considering factors that limit capacity to achieve environmental rehabilitation objectives, Miller (2016) distinguishes factors that were at least theoretically within the ability of management to influence, and those that were external to control (Table 3.5). Within the last class are listed factors imposed by regulation and / or corporate strategy, such as the complexity of objectives, and those that result from the environmental attributes such as rainfall reliability, and size and tractability of the species list required for rehabilitation. To this list can be added external economic factors, and knowledge and capability gaps (Table 3.5). In relation to those that are able to be managed, factors such as the extent and timing of impacts and rehabilitation requirements; topsoil and substrate management, trained personnel retention, availability of skilled contractors and rehabilitation resource management. A recent framework of biophysical questions that may require understanding or research to ensure support for the restoration of biodiverse ecosystems includes 34 high-order questions (Miller *et al.* 2016a). While these questions may not all be necessary for rehabilitation, as opposed to restoration projects, most of them are. Newton (2016) provides a long and detailed schedule for planning and implementation of rehabilitation of Banksia woodlands after sand mining, for each step, planning, resourcing and timing can be considered to be a risk point if not implemented or considered appropriately. The absence of this kind of knowledge, or failure to find or consider this knowledge, is another risk.

TABLE 3.5 Factors influencing the capacity of rehabilitation programs to reach their goals

External to project control	Within capacity to influence
Imposed by regulation or corporate strategy	**Resulting from mine plans and activities at the site**
• Attributes of the project goals, i.e.: – Stable cover. – Stable cover using native species: – Vegetation cover goals e.g. 60% v 90% of reference. – Any representative local community. – The original or pre-existing community: – Species richness goals e.g. 50% versus 70%of reference. • Timeframes for completion and reporting	The area concerned: • Spatial extent • Diversity of communities or domains impacted • Timeframes for preparation and completion
Force majeure • Economic, political, social or regulatory change. • Buy out, bankruptcy, market collapse **Resulting from the attributes of the site or environment** Attributes of the site, pre-mining: • Richness of the community – how many species. • The mix of species: – Number that can be returned from topsoil seed. – Number to be returned from: seed; greenstock; cuttings; tissue culture. • Number with known germination and/or propagation techniques: Complexity and reliability of techniques.	Availability, storage condition and viability of biophysical resources: • Root zone subsoil. • Topsoil: – As a growing medium (volume, suitability). – As a source of seed (collection, viability, storage and respreading conditions). • Viable collected seed. • Material (seed or cuttings) for propagation. • Mulch, wood piles.
Attributes of the site, post-mining: • Appropriateness for the target community: Landform – exposure to radiation, wind, erosion, slope stability. • Site hydrology: landform, soil texture and profiles to enhance infiltration and water retention. • Substrate physical and chemical properties. • Onsite threats (weeds, grazing, etc.). • Type and severity of impact (exploration track vs waste rock dump). • Site hostility: e.g. tailings vs drill pad. • Presence of toxic wastes, radioactive materials, acid drainage, etc.	Ability to mobilise/ manage resources: • Scheduling in relation to season: • Topsoil collection. • Collection and storage of seed. • Landforming and soil profile reconstruction. • Site treatments (ripping, fertiliser, irrigation, mulch, etc.). • Topsoil respreading. • Propagation of greenstock. • Seed treatments. • Application of seed. • Planting greenstock. Equipment and capacity: • Landforming, ripping, irrigation. • Propagation, nursery, seed store. • Seed treatments. • Seeding (direct seeding, broadcast seeding). Personnel, culture and knowledge: • Trained and experienced staff or contractors • Existence of, and ability to learn from, similar attempts in region • Willingness to invest in and extend best practice • Understanding of limitations, with willingness to invest in R&D or adaptive management
Events: • Reliance on episodic rainfall. • Fire, severe drought, storms-erosion. • Change in management or policy, downsizing.	Attributes of the site, post-mining: • Capacity to modify or amend post-mining conditions to suit the target community. • Capacity to modify the target community to suit the post-mining conditions (or to compromise). • Connectivity and edges. • Ability to manage threats. • Site security.

Source: adapted from Miller 2016

The extent of these challenges may guide decisions about the types of completion criteria used, their numerical targets and the rigor of monitoring and reporting appropriate for their assessment. These decisions are clearly relevant to regulators and other stakeholders when acceptable completion criteria for a project are considered. Many of the risks are amenable to management within a project but this ability, together with other risks, are attributes of the proponents: these proponent-risks should be considered realistically by all parties.

3.3.4 Effectiveness of risk controls

The evaluation of closure success is most commonly assessed in the context of rehabilitation failure. The Queensland closure guidance (DEHP 2014) is an example where rehabilitation failure is identified for consideration, as follows:

> *"Even if all criteria are met for several years, there is no guarantee that the rehabilitation will not fail in the future. The risk of failure is called the residual risk. A closure strategy, which is presented as a proposed control to reduce the residual risk is likely to be viewed as 'more robust' if it includes the propensity for failure. A risk assessment that considers the following should be used to determine how to calculate residual risk:*
>
> - *What components of the rehabilitation are most likely to fail (hazards);*
> - *The likelihood of failure; and*
> - *The consequences of failure."*

The uncertainty associated with the evaluation of closure success is also considered within Yukon Energy Mines & Resources (2013), which states that:

> *"While the Rehabilitation and Closure Plan (RCP) must describe robust measures and demonstrate how those are expected to achieve the reclamation and closure objectives and design criteria, there are often uncertainties and risks that may lead to unacceptable performance outcomes. The RCP should identify and characterize key risks and uncertainties, and provide measures for addressing them where possible."*

The development of risk ratings that could be utilised as a guide for evaluating closure success against key environmental risks would partially reduce the subjectivity associated with their assessment.

3.4 Selection of post-mining land uses

Two components of completion criteria development principles in Western Australia are that the completion criteria be agreed to by regulators, and be based on agreed PMLUs. The selection of PMLUs is a critical component required before closure objectives and completion criteria can be set. A two-stage process, PMLU selection should result from discussion between industry, regulators and key stakeholders (including likely or representative PMLU managers) to agree on the PMLU, but this discussion could benefit from application of a preliminary decision-making methodology. Cumulative impact assessment processes are also providing regional contexts for site-based PMLU decisions (Commonwealth of Australia 2018).

3.4.1 Decision-making tools

There are a number of well-established formal methodologies to facilitate decision making. Multi-attribute decision-making (MADM) can be used as a methodology to evaluate, compare and rank project alternatives against a set of criteria (Hajkowicz & Collins 2007). The decision maker assigns scores or weights to each criterion. Various methods exist for criteria-weighting and options-evaluation, such as multiple criteria utility functions, goals achievement matrix, goal programming, or Analytical Hierarchy Process (AHP) (Janssen 1992). In mine site rehabilitation, commonly applied MADM methods are Mined Land Suitability Analysis (MLSA), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and AHP (Narrei & Osanloo 2011; Soltanmohammadi *et al.* 2008, 2009, 2010). Within the MLSA framework, Soltanmohammadi et al. (2010) propose a list of eight broad end land uses (subdivided into 23 specific uses) and 50 evaluation criteria grouped into economic, social, technical and mine site factors. Following a series of comparisons and calculations, the AHP-TOPSIS approach results in preference ranking list for possible post-mining land uses. Variations of this framework have been proposed, for example, using 'fuzzy' AHP to deal with vague data (Masoumi *et al.* 2014) or incorporating spatial analysis (Palogos *et al.* 2017). Multi-attribute decision-making processes have been criticised for the subjective nature of the weightings that are chosen to represent the analyst's assessment of the relative importance of each criteria (Dobes & Bennett 2009; Ergas 2009), and for the use of overly complicated mathematical functions that obscure the decision-making process. This methodological complexity may also hinder the widespread application of MADM to guide post-mine land use decisions.

Land suitability assessments (LSA) or land capability assessment (LCA) are an important tool in Western Australia's rural planning system (van Gool *et al.* 2005). The assessments are based on the capacity of land to sustain specific land uses such as cropping, irrigated agriculture and forestry which could be used post-mining as well. Assessment of land capability considers the specific requirements of the land use and the risks of degradation associated with the land use (Rowe et al. 1981). LSA/LCA produces five land capability classes that define the suitability of land for a certain use.

Benefit-Cost Analysis (BCA) is the primary tool that economists use to determine whether a particular course of action (e.g. policy project or rehabilitation proposal) promotes economic efficiency (Kotchen 2010). In a BCA, all the impacts of an action, to all affected parties, at all points in time, are measured and expressed in a common monetary unit. If the present value of the benefits is larger than the present value of the costs, the project improves overall social welfare. It should be noted that BCA does not only incorporate the financial effects of a policy but should account for all the social cost and benefit impact, both financial and non-financial (non-marketed) values (Pearce *et al.* 2006).

3.4.2 Environmental offsets and approval conditions

Environmental offsets are an offsite action(s) to address the significant residual environmental impacts of a development or an activity (Government of Western Australia 2011, 2014). In Western Australia, offsets can form a key component of an approvals process and, together with direct requirements of the approval conditions, may dictate that the PMLUs for a specific area within a site is for conservation or a natural environment.

Offsets are a mechanism to provide environmental benefits to counterbalance the significant residual environmental impacts or risks of a project (Government of Western Australia 2011, 2014). The offsets are applied when there are residual impacts to rare and/or endangered species; areas within a formal conservation reserve system; important environmental systems and species that are protected under international agreements; and areas that are already defined as being critically impacted in a cumulative context. They may also be required when the impact causes flora or fauna to become endangered or it affects an ecosystem with an important ecological function (Government of Western Australia 2014).

Offsets may be direct or indirect through the forms of land acquisition, on-ground management or research projects. The type of offset depends on the impact predicted, the options for offsets in the vicinity of the project and the state of knowledge of the environment being impacted (Government of Western Australia 2014). In some cases, an environmental offset may be in the form of the ecological restoration of the impacted site or a nearby site, which will dictate the end land use.

May *et al.* (2016) reviewed the effectiveness of offsets approved between 2004 and 2015 in Western Australia, concluding that less than 40% of the 208 offsets studied were effective, according to simple measures. Relevant to completion criteria formulation and assessment, it was found that 18% of offsets were inadequately reported, and concluded that improvement is required to ensure approval conditions actually measure ecological outcomes.

3.5 Identifying an appropriate reference

The application of completion criteria for biological attributes typically relies on comparison with a reference state, concept, model or ecosystem. The SER International Primer on Ecological Restoration (SER 2004) identifies three strategies used to evaluate rehabilitated landscapes in relation to reference ecosystems:

- **Direct comparisons** result in completion criteria that can be directly measured and are based on data from reference sites. For example, reference site data may be based on detailed plant surveys and vegetation mapping.
- **Attribute analysis** seeks to confirm that essential criteria required for ecosystems to function have been reinstated. These criteria equate to the overall objectives of a rehabilitation project which ensure an ecosystem will continue to recover without further management inputs.
- **Trajectory analysis** looks at trends in ecosystem properties and functions that gradually recover towards a reference condition.

Each of these strategies requires a comprehensive understanding of the reference ecosystem (SER 2004). The SER Primer addresses ecosystem restoration, which, depending on project objectives, usually has different objectives to rehabilitation, and is defined as being on a pathway to a restored state, where the restored state matches the reference state in relation to the nine attributes listed in Table 3.6 (SER 2004). Use of a reference benchmark in rehabilitation does not mean that targets are necessarily equal to the reference state, but rather they are informed by it. That is, the criteria may be 90% of vegetation cover or 70% of species richness (for example), irrespective of the form of the reference, if agreed with stakeholders. Using a reference system is a critical aspect of achieving appropriate rehabilitation outcomes, as it provides a clear depiction of the long-term goals of the restoration project and a development state to evaluate against. However, there are a range of constraints, ranging from the abiotic to the biotic, that influence efforts to replicate natural ecosystems in mining landforms (EPA 2006). Abiotic factors include potentially-unfavourable properties of mine waste materials, while biotic factors include those associated with biodiversity and environmental threats such as weeds and disease.

When considering possible outcomes from mine rehabilitation, it needs to be recognised that landforms, substrates and hydrology are often altered such that return to pre-existing conditions may not always be practical (Gould 2011). A principle for development of completion criteria is that they should 'acknowledge the consequences of permanent changes to landforms, soils and hydrology'. This fact is a key reason why rehabilitation after mining activity often results in the appearance of an altered ecosystem (Doley & Audet 2013, 2016). Soil physical structure, and probably also soil biological and chemical properties, will be different to those of the site prior to mining. Other factors, such as slope and hydrological characteristics, will add further to the differences (Suding & Cross 2006, Stuble *et al.* 2017). These altered properties may make site conditions no longer well suited to support the pre-existing ecosystem, and vegetation attributes and rehabilitation development trajectories will differ from those in an undisturbed reference ecosystem. There are four approaches to this problem:

1 While the post-mining system, with its altered landform, hydrology and soils, is altered from its pre-mining state, it may be more like other natural system analogues. If, for example, the site is now more arid, rocky or saline, and if there are natural regional analogues, it may be possible to identify a natural ecosystem from the region that is a more achievable objective. This may result in a more natural, although still different, outcome (Garrah & Campbell 2011);

2 Consider the site attributes that most differ and implement elements to mitigate the difference – by blending growth media, adjusting rehabilitation site substrate profiles, adding amendments and so on (Rokich *et al*. 2000; Erickson *et al.* 2016) – in order to maximise the chances of succeeding with a pre-mining reference;

3 A mixture of the above approaches, whereby a regional ecosystem different to the pre-existing state is employed as a reference, and the site is adapted to make it better able to support that community; and

4 Agree on a different or novel ecosystem or land use – if appropriate.

Identifying key ecosystem attributes relies on adequate understanding of the reference ecosystem, particularly the composition (species), structure (complexity and configuration) and function (processes and dynamics) (SERA 2017). There are few Western Australian ecosystems that have this level of understanding. The most notable exception is the jarrah (Eucalyptus marginata) forest which has been the subject of substantial rehabilitation-related research over several decades driven primarily by bauxite mining operations (e.g. Gardner & Bell 2007) – see Section 5.6.3 for details. While there are still advances to be made in the level of understanding of the jarrah forest ecosystem, the vast majority of Western Australian mining operations do not have the same level of ecological understanding, but with appropriate resourcing in research could rapidly progress at least the basics of this knowledge.

Given that vegetation composition is a typical attribute measured in rehabilitated areas, it is critical that aspects such as successional patterns are well understood. In Pilbara ecosystems, for example, it is typical for early vegetation to be dominated by short-lived colonising species at relatively high densities which, after time, give way to a different vegetation profile dominated by long-lived perennials at low density. There is often a lack of natural recruitment into rehabilitated areas (e.g. Norman 2006; Bellairs 2000) and for this reason, the early establishment of plant species richness is essential. With best practice, this may be achieved early in mine site rehabilitation in Western Australia, with those sites subsequently exhibiting trends of decreasing species richness and increasing vegetation cover with time. These predictable successional processes are not always reflected in the structure of completion criteria, particularly if vegetation parameters are treated together and expected to exhibit similar trends with time. Using the post-disturbance trajectories of the reference system – such as after fire in many natural systems – may be a mechanism to benchmark against this dynamism.

Photo courtesy: Renee Young

This is not yet a well-used approach, and it is possible that there are pragmatic or ecological reasons why the numeric value of the criterion should vary with time (e.g. 90% of the benchmark during establishment and 70% subsequently). However, this has not been explored.

Pit lakes are an alternative land use (rather than a novel ecosystem – they are just new lakes) where there are no obvious reference or analogue sites (Blanchette & Lund 2016). Blanchette and Lund (2016) speculated that the natural evolution of pit lakes is limited by low levels of carbon. However, our understanding of the ecology of pit lakes and their catchments across Western Australia or Australia is limited. River diversions and river alterations at closure also pose challenges for traditional use of reference sites as each site is directly influenced by all sites upstream and small alterations in hydrology can have profound effects on geomorphology and biota. Blanchette and Lund (2017) and Blanchette et al. (2016) use a 'systems variability' approach to define whether rehabilitation is successful without the need for reference sites and using standard ecological monitoring approaches.

An alternative approach to using undisturbed reference sites is to use an actual rehabilitation outcome, if acceptable, at the mine site as the benchmark for completion criteria for future rehabilitation (Mine Earth 2013). Essentially, it recognises that there may not be sufficient knowledge to define adequate performance in terms of specific attributes in a reference ecosystem. This approach has been accepted at very few sites and presents a risk of low standards of restoration becoming accepted and replicated across multiple sites. It would be critical for this approach to demonstrate a clear understanding and documentation of the methods used to achieve the reference rehabilitation and a clear plan to replicate or improve on it. As part of that, a related program of research-focused monitoring should be instigated to ensure continuous improvement.

3.6 Attributes relevant to mine closure

International, national and state guidelines for mine closure identify many different attributes that can be used in the definition of completion criteria. Although most guiding documents list similar attributes, the terminology is often inconsistent, with no document providing a single, comprehensive attribute list. To bridge this gap, a thorough literature review for the environmental attributes was carried out including guidelines, scientific papers and expert consultation. This table was then expanded upon to also include non-environmental attributes to provide a single consolidated list for the definition of completion criteria. The non-environmental attributes provided have not been through the same scientific review process as the environmental attributes, rather populated via input from DMIRS, DWER and industry consultation. A formal review of non-environmental aspects, attributes and monitoring is identified as a gap and a recommended as future project to support revised versions of this report. References that provide further information on listed attributes are also included.

It is worth noting that while in this review attributes have been presented in the specific context of aspects of mine closure, SERA (2017) proposed an alternative grouping framed from a broader ecological perspective, which is appropriate for all restoration projects (Table 3.6). While focussed on restoration, both SER and SERA attributes are also broadly applicable to mine closure and the more detailed level of specific attributes considered in this review would also fall within these broader ecological descriptors.

TABLE 3.6 Broad alignment of aspects from local and international guidelines for rehabilitated and restored ecosystems

	SER (2004) Restoration Attribute	EPA (2006) Rehabilitation criteria	SERA (2017) Restoration attribute
Physical	4. Physical environment	1. Safe, stable, suitable for agreed use without inputs 2. Heritage and visual amenity 3. Appropriate hydrology 4. Acceptable off-site impacts 5. No major pollution, acid soils *6. Soil structure and function	Physical conditions
Biodiversity	1. Structure 3. Functional groups	9. Abundance or density 12. Canopy and keystone species 16. Habitat diversity	Community structure
Biodiversity	1. Structure 2. Indigenous species 3. Functional groups	8. Species diversity 10. Genetic diversity 11. Ecosystem diversity *13. Effective weed control 15. Animal diversity	Species composition
Biodiversity	8. Resilient 9. Self-sustaining 5. Function	*6. Soil structure and function 7. Self-sustaining and resilient	Ecosystem function
Biodiversity	6. Landscape integration 7. External threats	*13. Effective weed control 14. Pest and disease control	External exchanges Absence of threats

* Criteria repeat in two attributes.
Note: aspects are defined as criteria and attributes in source documents.

Attributes relating to physical and chemical aspects of waste materials and soils in rehabilitated mine sites are well established, whereas attributes and their measurement relating to biological elements are more dynamic, reflecting the advances in technology, for example in DNA sequencing (Muñoz-Rojas 2018). In addition, it should be recognised that processes and interactions in ecosystems are complex, often relatively poorly understood for Western Australia ecosystems, and the subject of substantial current research.

As an example of the large number and diversity of environmental attributes that could be considered for use in completion criteria, Wortley *et al.* (2013) reviewed 301 articles related to assessing restoration and found that the biological attributes used could be classified broadly into: 'vegetation structure'; 'ecological processes'; and 'diversity and abundance'. Vegetation structure was included in 118 papers (39%), most commonly in combination with diversity and abundance measures. Ecological processes were measured in 127 papers (42%) in total, with the most common topics being: nutrient cycling, soil structure or stability; dispersal success/ mechanisms, faunal activity and carbon storage. Attributes in the final category, diversity and abundance, were the most frequently measured with 213 papers (67%), in which about two thirds used flora and 40% used fauna. The diversity and abundance of invertebrate fauna (48 papers) were measured more frequently than vertebrates (34 papers). More specifically, Muñoz-Rojas (2018) listed 20 key soil indicators with application to restoration, and highlighted developing molecular technologies and spectroscopic techniques with potential application. Similarly, Jasper (2002) reviewed more than 40 research papers dealing with soil quality in agriculture or mine rehabilitation and identified 58 individual measures of soil properties or processes, including 22 physical, 15 chemical and 21 biological measures. Selection of attributes that best suit the practical purpose and timeframe of mine closure and relinquishment is a key challenge faced by mining companies.

Attributes to be considered for completion criteria range from those that can be directly verified or measured on the site itself, through to sensitive receptors that may be offsite, but with potential to be affected by a factor associated with the closed mine through an exposure pathway. This section aims to present a comprehensive list of attributes that could be used in completion criteria for Western Australia mine sites (Table 3.7). In the following section, considerations for selecting attributes are discussed, and a recommended list of appropriate attributes presented.

Photo courtesy: Mike Young

TABLE 3.7 Attributes applicable for the definition of completion criteria identified from the reviewed references

Few attributes are appropriate for all settings, while others not listed may also be valuable: the list focusses on environmental attributes, but also provides some as indicators for other aspects. The most recommended attributes (based on considerations of Section 3.6.1 *Attribute selection*) are indicated in grey shading).

Aspect	Biotic	Possible attributes	Type*	References
Water and drainage	Abiotic	Design and construction of landforms and drainage features	P	Barritt *et al.* (2016)
	Abiotic	Quality, quantity and fate of surface water flow	Q	ANZECC & ARMCANZ (2000a); ANZECC & ARMCANZ (2000b); Smith *et al.* (2004b)
	Abiotic	Integrity of drainage structures	Q	
	Abiotic	Connectivity with regional drainage (lakes and rivers)	Q	
	Abiotic	Pit lake bathymetry	P/Q	Blanchette & Lund (2016, 2017); Blanchette *et al.* (2016); McCullough & Lund (2006)
	Abiotic	Pit lake sediment quality	Q	
	Abiotic	Pit lake water quality	Q	
	Abiotic	Surface water quality, quantity and timing	Q	
	Abiotic	Surface water chemistry and turbidity	Q	
	Biotic	Aquatic biota (algae, macrophytes; invertebrate and vertebrate fauna)	Q	
	Biotic	Riparian vegetation	Q	
	Abiotic	Surface water chemistry and turbidity	Q	ANZECC & ARMCANZ (2000a); ANZECC & ARMCANZ (2000b); Smith *et al.* (2004b)
	Abiotic	Groundwater chemistry	Q	
	Abiotic	Direction and quantity of groundwater flows	Q	LPSDP (2016h); LPSDP (2016e)
	Abiotic	Level of groundwater table	Q	LPSDP (2016h); LPSDP (2016e)
	Abiotic	Treatment, discharge and disposal of poor-quality water and sewage	Q	
Mine waste and hazardous materials	Abiotic	Landform design & construction	P	Barritt *et al.* (2016); LPSDP (2016b, 2016e, 2016g)
	Abiotic	Residual alkalinity	Q	LPSDP (2016g, 2016f, 2016c)
	Abiotic	Particle size and erodibility	Q	Moore (2004); LPSDP (2016e, 2016c)
	Abiotic	Strength	Q	
	Abiotic	Acid, alkali or salt production potential	Q	INAP (2009); LPSDP (2016e, 2016g, 2016f, 2016c, 2016h)
	Abiotic	Total and soluble metals and metalloids	Q	
	Abiotic	Spontaneous combustion potential	Q	INAP (2009); LPSDP (2016e, 2016c)
	Abiotic	pH and electrical conductivity	Q	INAP (2009); LPSDP (2016e, 2016g, 2016f, 2016c, 2016h)
	Abiotic	Radiation	Q	INAP (2009); (LPSDP 2016e, 2016c)
	Abiotic	Asbestiform minerals	Q/P	
	Abiotic	Design and construction of containment structures for hostile wastes	P	INAP (2009); (LPSDP 2016g, 2016f, 2016c)
	Abiotic	Physical integrity of containment structures for hostile wastes	Q	
	Abiotic	Dust	Q	LPSDP (2009)
	Abiotic	Sediment quality	Q	ANZECC & ARMCANZ (2000a); ANZECC & ARMCANZ (2000b); Smith *et al.* (2004b)
	Biotic	Plant metal uptake	Q	
	Abiotic	Other types of waste: fuels, lubricants, detergents, explosives, solvents and paints	Q/P	LPSDP (2016e)

* **Type:**
P = installed/built as planned – a process for emplacing these attributes is approved initially and then certified as and when constructed;
C = categorical – the feature is required to be present or absent;
Q = quantitative – the attribute can be measured and compared against a numerical target.

Table 3.7 continues following page...

TABLE 3.7 Attributes applicable for the definition of completion criteria identified from the reviewed references

Aspect	Biotic	Possible attributes	Type*	References
Physical and surface stability	Abiotic	Soil coarse fraction content	Q/P	
	Abiotic	Soil fraction particle size analysis (texture)	Q	LPSDP (2016e)
	Abiotic	Hydraulic conductivity	Q	Moore (2004)
	Abiotic	Sodicity, slaking and dispersion	Q	
	Abiotic	Clay mineralogy	Q	
	Abiotic	Soil strength	Q	
	Abiotic	Surface resistance to disturbance	Q	
	Abiotic	Erosion rills, gullies, piping	Q	
	Abiotic	Sediment loss	Q	
	Abiotic	Placement of appropriate surface materials	P/Q	
	Abiotic	Tailings storage facilities (TSFs): Structural stability	Q	LPSDP (2016d, 2016e)
	Abiotic	Tailings storage facilities (TSFs): Compatibility with surrounding landscape and PMLUs	P	
	Abiotic	Earthworks as designed	P	LPSDP (2016c, 2016c)
	Abiotic	Subsidence	Q	
Soil fertility and surface profile	Abiotic	Soil texture (particle size distribution)	Q	Moore (2004); INAP (2009); DEC (2010)
	Abiotic	Slaking, dispersion and sodicity	Q	
	Abiotic	Compaction	Q	
	Abiotic	Stability of surface drainage lines	Q	
	Abiotic	Bulk density, depth of ripping and soil strength	Q/P	
	Abiotic	Aggregate stability	Q	
	Abiotic	Water infiltration	Q	
	Abiotic	Plant-available water	Q	
	Abiotic	Soil profile as designed	P/Q	
	Abiotic	Electrical conductivity	Q	
	Abiotic	Nutrient pools (N, P, K, S)	Q	
	Abiotic	Plant-available nutrients; cation exchange capacity	Q	
	Abiotic	Heavy metal bioavailability	Q	
	Biotic	Organic carbon (total, labile, microbial)	Q	
	Biotic	Microbial activity (respiration, enzyme activity)	Q	
	Biotic	Microbial taxonomic and functional diversity (genetic, physiological)	Q	
	Biotic	Soil invertebrate abundance and composition	Q/C	
	Biotic	Presence of specific functional soil microbial populations (e.g. mycorrhizal fungal abundance, N-fixing bacteria)	Q/C	
	Biotic	Root pathogens	Q	
	Biotic	Biological surface crust formation (cryptogram cover)	Q	
	Biotic	Proportion of area receiving topsoil	P	

Table 3.7 continues following page...

TABLE 3.7 Attributes applicable for the definition of completion criteria identified from the reviewed references

Aspect	Biotic	Possible attributes	Type*	References
Flora and vegetation	Biotic	Numbers of species and quantities of viable seed in seed mix	P	LPSDP (2016d, 2016a, 2016b, 2016f)
	Biotic	Number of seedlings planted	P	
	Biotic	Plant stem density	Q/P	
	Biotic	Vegetation cover	Q	
	Biotic	Vegetation productivity (biomass, foliar cover, height)	Q	
	Biotic	Species richness	Q	
	Biotic	Species diversity (richness, evenness)	Q	
	Biotic	Vegetation composition	Q	
	Biotic	Litter cover	Q	
	Biotic	Presence/abundance of keystone, priority or recalcitrant species	Q/C	
	Biotic	Presence of key functional groups	Q/C	
	Biotic	Community structure – presence of all strata	Q/C	
	Biotic	Community structure – patchiness, gaps, banding	Q/C	
	Biotic	Palatable & and non-palatable species	Q	
	Biotic	Disease-resistant species	Q/C	
	Biotic	Weed species presence and abundance	Q/C	
	Biotic	Condition of sensitive communities	Q/C	
	Biotic	Aquatic biota (algae, macrophytes; invertebrate and vertebrate fauna)	Q	
	Biotic	Riparian vegetation establishing	Q	
Flora / habitat	Abiotic	Constructed habitat features (breeding and refuge)	P	
	Biotic	Vegetation and litter habitat (foraging, breeding and refuge, in general or for conservation significant species)	Q	
	Biotic	Habitat complexity	Q	
	Biotic	Species presence, abundance and composition (terrestrial and aquatic, invertebrate and vertebrate)	Q/C	
	Biotic	Presence of vertebrate pests	Q/C	
	Biotic	Subterranean fauna (stygofauna and troglofauna)	Q	
	Biotic	Species and quantities of viable seed in broadcast seed – for fauna requirements	P	
	Biotic	Seedlings planted – for fauna requirements	P	
	Biotic	Indicator species abundance	Q	
	Biotic	Indicator species group richness and composition	Q	
	Biotic	Presence of keystone or significant species	Q/C	

Table 3.7 continues following page...

TABLE 3.7 Attributes applicable for the definition of completion criteria identified from the reviewed references

Aspect	Biotic	Possible attributes	Type*	References
Ecosystem function and sustainability	Abiotic	Rainfall capture & infiltration	Q	
	Abiotic	Soil surface stability	Q	
	Abiotic	Bare ground area, largest gap size	Q	
	Biotic	Biological surface crust formation (cryptogram cover)	Q	
	Biotic	Nutrient cycling (nutrient retention/loss pathways, trophic food webs)	Q	
	Biotic	Soil microbial function – solvita, respiration	Q	
	Biotic	Presence of different successional groups	Q/C	
	Biotic	Indicator species group richness and composition	Q	
	Biotic	On site nesting / breeding of fauna	Q/C	
	Biotic	Plant growth, survival, rooting depth, physiological function	Q	
	Biotic	Plant species reproduction and recruitment: Flower, seed production, seedbanks	Q	
	Biotic	Capability for self-replacement: seedbanks, seedlings mature 2nd generation	Q	
	Biotic	Connections with nearby systems in place, functioning: corridors; pollinator, gene movement	Q/P	
	Either	Offsite impacts absent or managed: dust, groundwater, disturbance	Q/P	
	Either	Key threats absent or managed: feral grazers, predators, pathogens, weeds, etc	Q/C/P	
	Biotic	Resilience to long-term climate trends	Q	
	Biotic	Resilience to disturbance (such as fire, drought, extreme weather events)	Q	
	Biotic	Feed on offer, livestock, timber, grain productivity (production PMLUs)	Q	
Social / economic	Aspect out of scope for this report: range of indicative attributes only	Recreation opportunities provided, maintained	P	ICMM (2003, 2008, 2012)
		Heritage values protected	P	
		Aesthetics (Visual Amenity)	P	
		Other ecosystem service provision	Q	
		Access and safety	P	
		Infrastructure removed	P	
		Sustainability of utilities	P	
		Land tenure (e.g. site is incorporated into conservation reserve)	P	
		Social progress: Health, education, employment, livelihoods and incomes	P/Q	

* **Type:**
P = installed/built as planned – a process for emplacing these attributes is approved initially and then certified as and when constructed;
C = categorical – the feature is required to be present or absent;
Q = quantitative – the attribute can be measured and compared against a numerical target.

3.6.1 Attribute selection

Considerations

While the number of possible indicators is very large (c.f. Table 3.7), selected attributes should be appropriate to the location, and relevant to the defined closure objectives and identified risks. Attributes that measure key components of early development in ecosystems are particularly important. The challenge is to identify biological indicators that are both meaningful and practical to measure. In Queensland, proponents are obliged to justify the selection of attributes used in criteria, including how the relationship between the criteria and rehabilitation objective has been established, supported by references to authoritative sources or relevant monitoring data (DEHP 2014).

The selected attributes used in criteria should be relevant to PMLUs, and meaningful and measurable. In addition to the principles for completion criteria described in Table 3.2 (e.g. SMART), some important requirements of attributes included in completion criteria, (e.g. EPA (2006); DMP & EPA (2015); Jasper (2002), are as follows:

- Address priority aspects;
- Be significant for rehabilitation outcomes;
- Measure an element that can be directly managed or remediated;
- Have manageable sampling intensity;
- Have low error associated with measurement, including reliable data capture from different observers;
- Have available interpretation criteria: no ambiguity in interpretation;
- Hove local reference data available or able to be sourced;
- Be responsive in appropriate timeframes, and
- Be reproducible and auditable by a third party.

A list of attributes, with recommendations based on these factors, is given on the previous pages in Table 3.7.

A number of issues should be considered when selecting attributes that are most useful for completion criteria for mine rehabilitation and closure in Western Australia for PMLUs that include ecological objectives. Leading versus lagging indicators; successional change and dynamism; fauna return; temporary water bodies and; climate and climate change are discussed below.

Leading versus lagging indicators

Completion criteria aim to determine whether a domain has reached its desired state or is on a desired trajectory. It is useful to establish criteria that may be able to provide information on performance sufficiently early to allow a timely management response, if required, on the rehabilitated area. If completion criteria are not able to be expressed in this manner, it may still be valuable for managers to develop interim targets and / or appropriate monitoring for early detection. Two important reasons to move the focus of criteria to early, or ‘leading’, indicators are:

- An early assessment of adequacy of revegetation makes it more practical and cost-effective for mining operations to be able to mobilise machinery and other resources required for remedial works; and
- In most Western Australian ecosystems, there is likely to be relatively little passive recruitment into revegetated areas after initial establishment (e.g. Norman *et al.* 2006; Stantec 2015), making it critical to focus on the early establishment stage to ensure revegetation success.

In the context of mine closure, it is a challenge to rely on criteria which may take many years to be evaluated (Figure 3.1). In these circumstances, lagging indicators may be not practical because of the time required to assess success of the measured attribute. In general, a focus on improving understanding of the most appropriate starting conditions (e.g. soils, initial plant populations, nutrient levels) is likely to be required to consistently give the best rehabilitation outcome.

The value of focussing on initial establishment is demonstrated in current completion criteria for Alcoa’s bauxite operations. As explained in the case study Section 5.6.3, the stocking rate of Eucalyptus species and density of legumes at nine months, and species richness and density of re-sprouter species at 15 months, are the four key measures of rehabilitation adequacy (Alcoa 2015). Importantly, these parameters are measured early enough so that it is relatively practical to remediate, if required. Reliance on these four criteria, measured at early stages of vegetation, is made possible because of the substantial research base that has been established, and stakeholder confidence in Alcoa's consistent application of a well-defined rehabilitation procedure. The model of relatively simple completion criteria that are based on a detailed understanding of ecosystem development processes and outcomes, and on consistent rehabilitation practices, is directly applicable for all mining operations.

In contrast to the high level of understanding of re-establishment of ecosystem structure and function after bauxite mining in the northern jarrah forest, there is a relatively limited understanding of the most appropriate rehabilitation strategy for local ecosystems (and particularly pit lakes) at most Western Australian mine sites. Inevitably, this leads to a lack of certainty in the outcome, which in turn makes measures of long-term ecosystem development unworkable as completion criteria. Improved understanding of the most important elements required to be in place at the outset will then provide a basis for defining appropriate criteria as leading indicators, and place the focus on critical early phases of landform design, soil reconstruction and vegetation establishment.

Indicators need to be a measure of, or directly linked to, an attribute that most strongly correlates with trajectory towards, or likelihood of achieving, desired final states, as well as being something that can actually be managed and remediated during closure execution, as required. For example, in relation to vertebrate fauna return to a rehabilitated ecosystem, a leading criterion may be the number of constructed fauna habitats, and or re-establishment of key plant species that provide physical or foraging habitat. If these habitat elements are inadequate, there is an opportunity to correct them during closure. By contrast, the actual timing and extent of return of the fauna species of interest to rehabilitated areas is inherently uncertain, making it less suitable as completion criteria. Even if fauna return was a direct reflection of the adequacy of rehabilitation efforts, it remains a lagging indicator because it may not be fully measurable until after development of suitable habitat. It has also been found that early return of bio-indicator species, such as ants, may be a poor predictor of longer-term outcomes (Majer *et al.* 2013). Additionally, in pit lakes, our understanding of faunal establishment and development is very poor (see McCullough and Lund 2011). However, monitoring fauna to understand their response to the re-established ecosystem is valuable, including their use of constructed habitats, because it informs continual improvement in the rehabilitation approach.

Photo courtesy: Alcoa

Dynamic references and rehabilitation trajectory

Selected references are often a mature phase of vegetation or community, whereas rehabilitation is usually still on a trajectory, hopefully, towards the mature phase state. Dynamic targets can be developed based on the behaviour of a dynamic reference if there is an appropriate reference process for this purpose (Figure 3.1). Fire is a common natural disturbance in many Western Australian ecosystems and may provide this opportunity. Even if the sequence of dynamic references is not available, comparing rehabilitation and references at one time when they are the same age since disturbance/establishment may be useful.

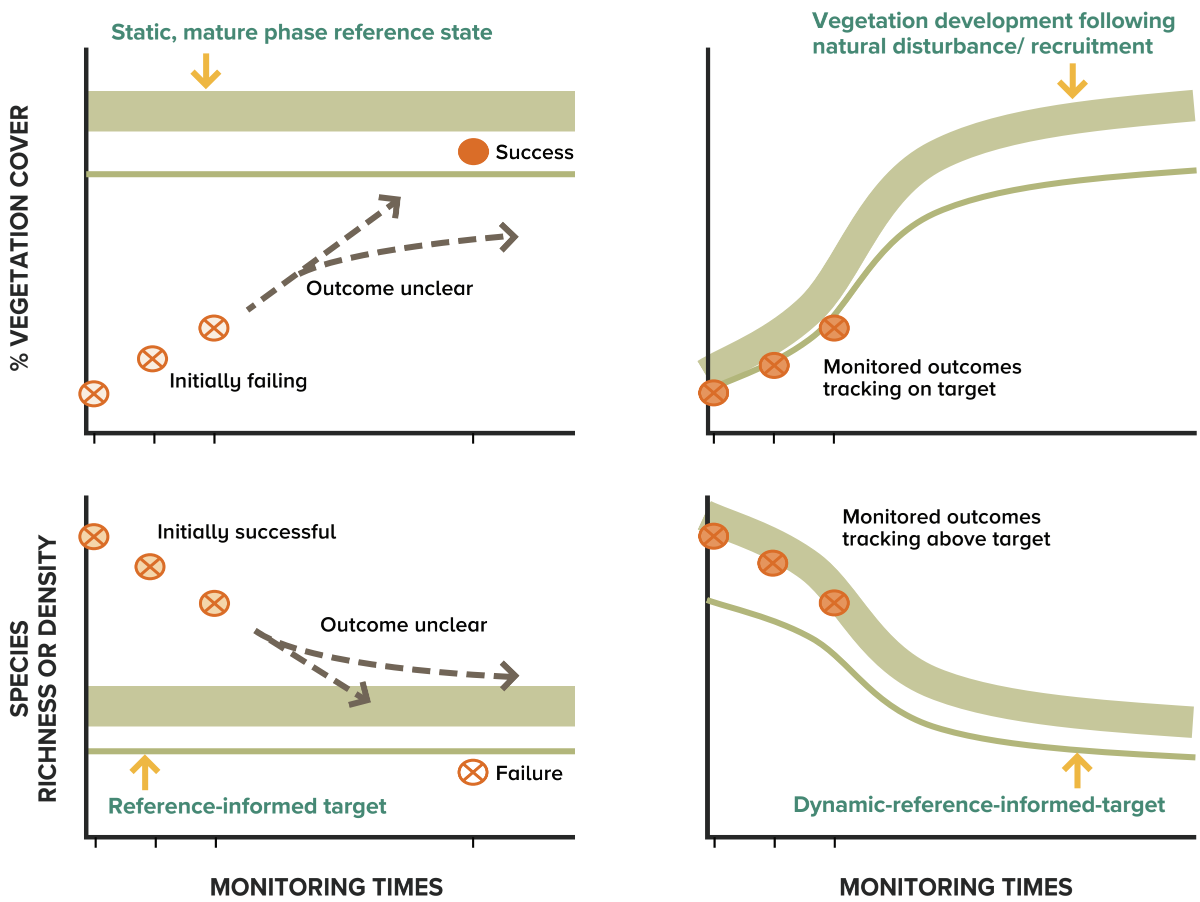


FIGURE 3.1 Monitoring models of restoration
Restoration with a mature phase **(left)** versus a developing-vegetation dynamic reference **(right)** for indices which increase over time **(top**; e.g. Vegetation Cover) and for indices which decline over time **(bottom**; e.g. Species Richness).

Monitoring based on a static reference state cannot allow strong inference of final outcomes unless the rehabilitation reaches or passes the target. Over the long-term success, but not failure can be confirmed for metrics that increase through time, and failure but success can be confirmed for those that increase through time. Comparing rehabilitation to a reference trajectory based on a dynamic developmental sequence apparent in the reference system that occurs following a natural disturbance or episodic recruitment event such as fire allows continual assessment against a dynamic reference and more informed prediction of the likelihood of success at any time.

Ecological parameters often have a predictable trajectory in natural systems after disturbance, some increasing others decreasing. Table 3.8 indicates common trajectories in attribute values that vary over time in rehabilitation. Some, such as weed cover, may vary in trajectory across sites depending on the identity of the weed species.

TABLE 3.8 Common directions of change in environmental metrics after rehabilitation

Direction	Metrics
Increasing	• Plant cover • Weed cover • Structure and structural complexity • Litter and nutrient cycling • Soil carbon • Fungi and soil biotic function • Similarity of soil microbial community to reference • Compositional similarity to reference • Flowering and seed production • Habitat elements for many fauna (hollows, logs) • Resilience
Little change	• Compositional similarity to reference • Weed cover
Decreasing	• Tree or plant density • Species richness • Bare ground • Weed cover • Erosion

Fauna return in the context of completion criteria

Vegetation parameters are established as the most common completion criteria and are often assumed to be effective surrogate for all other types of organisms. However, this is not always the case (Cristescu *et al.* 2012; Cross *et al.* 2019) and, thus, further work is required to validate recovery trends for fauna in a wide range of habitats (EPA 2006). Soil micro-fauna are typically brought to rehabilitated areas with respread topsoil, if collected and stored appropriately (Jasper 2007). Invertebrate fauna may also be introduced through topsoil or may recolonise from adjacent areas. Vertebrates are usually the last to recolonise, once complex vegetation assemblages and invertebrate prey are established (Thompson & Thompson 2006). Clearly, faunal successional sequence is complex and will not always be completed within required timeframes (Brennan *et al.* 2005). In addition, the presence of fauna within rehabilitation areas does not always indicate permanent, successful recolonisation (Gould 2011). The lagging nature of fauna monitoring outcomes may mean that it is best suited as a research tool rather than a completion criterion, assessing the effectiveness of current rehabilitation works for the purpose of informing further improvement, if appropriate leading indicators are available (LPSDP 2016b).

Challenges posed by water bodies

There are a range of attributes related to surface waterbodies including abiotic (water and sediment quality), hydrological characteristics (volume, flow and frequency) and biotic components (algae, macrophytes, invertebrate and vertebrate fauna). Principles that underlie guidelines such as ANZECC & ARMCANZ (2000a) have limited application to intermittent and permanent lakes and rivers, particularly in relation to mining impacts (Smith *et al.* 2004b). Smith *et al.* (2004b) review methods for water quality assessment of temporary streams and lakes, assessing the suitability of chemical and biological methods available, and providing broad recommendations.

While any number of chemical and biological indicators may be suitable for monitoring purposes, the key to effective monitoring is to first establish an understanding of the natural variability of the system. This includes seasonal fluctuations, which can vary substantially particularly in intermittent waters. Once this natural variation in baseline conditions is understood, completion criteria can be developed based on robust statistical analyses. These criteria can be utilised for comparison over time.

For waterbodies, relevant completion criteria can be established for water and sediment quality, and aquatic biota. For the former, this may involve deriving trigger values according to the upper limits of baseline data ranges, and for the latter this may comprise developing indices related to species richness (diversity), abundance and or composition.

Aquatic biota groups typically employed for completion criteria include algae, such as diatoms, and/or aquatic invertebrates (Lund & McCullough 2011; McCullough & Lund 2011) both of which are ubiquitous and are often numerically abundant. These groups are also associated with taxa that have mostly well-documented tolerance limits in the scientific literature or in specialist consultant databases. Well-defined tolerance limits of these organisms allow for comparison of monitoring data over time, and against ambient environmental conditions. The success in the use of these organisms is also linked to the experience of the taxonomists involved. Although the impact of water quality on macroinvertebrate diversity is reasonably well understood, factors such as habitat and food resources that might limit macroinvertebrate diversity in pit lakes is poorly understood (McCullough & Lund 2011). Using DNA analysis to investigate microbial assemblages (Blanchette & Lund 2018) and increasingly other aquatic fauna offers challenges and opportunities to the development of completion criteria. In addition, a more holistic approach should be undertaken for the assessment of waterbodies, where several environmental attributes such as aquatic invertebrates and algae may be measured in relation to factors such as salinity, to ensure that the desired outcome for completion criteria has been achieved. Usually these criteria may include an objective that the abiotic and biotic attributes of an aquatic ecosystem are comparable to natural or reference waterbodies in the region (although see Blanchette & Lund 2017 and Blanchette *et al.* 2016 for a counter argument).

Recognising the constraints of climate

Successful establishment of vegetation in rehabilitated areas depends on adequate rainfall at the time when viable seeds are present. The timing and amount of rainfall is unpredictable over much of Western Australia, meaning that rehabilitation outcomes may vary strongly from year to year. In a recent study of rehabilitation after iron ore mining, Shackelford *et al.* (2018) found that rainfall timing and quantity in the first two years of establishment was critical to revegetation outcomes. Higher rainfall in the first year was generally associated with greater plant density and cover in rehabilitated areas. Ensuring that rehabilitation activities are timed to coincide with most favourable climatic conditions is an important step in successful rehabilitation outcomes. Establishing timeframes for assessment that take into account this factor is critical in these systems. At the same time, developing techniques that may be able to ‘wait’ for good conditions may be an additional response.

There is debate in the field of restoration ecology as to how feasible it is to consider a changing climate in restoration practices in order to maximise long-term sustainability outcomes. One approach is to maximise genetic diversity in the system, potentially increasing diversity compared to the pre disturbance ecosystem. This may involve greater flexibility in considerations of appropriate provenance for plant species used in seed collection programs for site rehabilitation (Broadhurst *et al.* 2008). This will require greater understanding of the physiological tolerance zones of key perennial species to a changing climate, for example the drying trend exhibited in south-west Western Australia or the increased frequency of extreme weather events (Hancock *et al.* 2018). Embedding networked and standardised experimental trials into restoration activity has been identified as an approach that will support improved decision making for climate resilient restoration planning (Prober *et al.* 2018).

3.7 Monitoring environmental attributes

Within the mining context, monitoring can be defined as the gathering, analysis and interpretation of information for the assessment of performance (LPSDP 2016a). A separate process is auditing, which is the systematic review of monitoring procedures and results, to check that all commitments have been fulfilled by comparing the findings against agreed criteria. Although monitoring and auditing are separate processes entailing different methods and outcomes, they often come together under ‘monitoring and maintenance frameworks’ outlined by mine closure planning guidelines (ANZMEC & MCA 2000; ICMM 2008; DMP & EPA 2015). For example, according to the ICMM Planning for Integrated Closure Toolkit (ICMM 2008), closure monitoring programs need to establish: baseline conditions; quantification of changes that might occur; how progression towards goals can be measured; and how the achievement of goals can be demonstrated.

Following cessation of mining, monitoring should continue until it can be demonstrated that closure outcomes and completion criteria have been met (ANZMEC & MCA 2000; DMP & EPA 2015). It is often unlikely that many ecological conditions can be met within less than five years, while minimum monitoring periods after closure are usually in the order of 10 years. In Western Australia (DMP & EPA 2015), mine closure plans must provide appropriate detail on their monitoring procedures for each of their closure criteria. Closure monitoring frameworks shall include a number of items, such as methodologies (sampling, analysis and reporting), receiving environments, exposure pathways, reference trends and quality control systems.

In line with international standards (ANZMEC & MCA 2000), monitoring plans in Western Australia must also provide contingency and remedial strategies to be applied when indicators show a risk that completion criteria may not be met. This is understood as a risk-based approach, when monitoring and auditing results are used to review and refine completion criteria towards acceptable and realistic targets. Risk-based monitoring and auditing also has the advantage of reducing uncertainty in closure costs and contributing to orderly and timely closure outcomes.

3.7.1 Key monitoring methodologies

Given that completion criteria should be quantifiable, repeatable and auditable, it is good practice to create criteria that are amenable to statistical assessment. Arguably, a higher standard of evidence may be required to ensure that completion criteria have been met for attributes with higher levels of risk.

Monitoring programs should be designed to unambiguously and effectively answer the question posed by each completion criteria, and this requires appropriate sampling design. The way that completion criteria are formulated may also influence monitoring design and, indeed, completion criteria formulation should take into consideration the consequences for monitoring. For example, if completion criteria are expressed relative to a threshold (e.g. weed cover not more than a nominal percentage), then sampling needs to demonstrate that all sites are on the correct side of the target value. On the other hand, if completion criteria are expressed as being 'similar to' a target, then statistical tests of difference are required which take into account the average values of weed cover in both the rehabilitated and reference site samples and their variation.

This section discusses monitoring approaches for assessing completion criteria and identifies a range of techniques available for several key attributes and issues surrounding their use. It primarily focusses on ecological parameters relevant for completion criteria that are employed in various guidelines for rehabilitation and restoration (SER 2004; Wortley *et al.* 2013; SERA 2017) and in related literature (Ruiz-Jaén & Aide 2005a, 2005b; Lechner *et al.* 2012; Miller *et al.* 2016b).

The scientific literature that reviews monitoring methods in rehabilitation focuses on rehabilitation monitoring methods that are published in scientific studies. These may not represent a complete sample of appropriate monitoring approaches, project types and post-mining land uses, and would over-represent those with associated research projects. For example, Ruiz-Jaen and Aide (2005a), Matthews and Endress (2008) and Wortley *et al.* (2013), review the types of measures employed in published scientific literature to assess 'ecological restoration'. These reviews find that most studies focus on one, or two, of three types of attributes: measures of diversity and abundance are most frequently reported, followed by measures of vegetation structure, and of ecological functioning. Wortley *et al.* (2013) suggest that diversity and abundance measures are employed in the majority (76% in their analysis) of studies, as they represent a primary objective of restoration, but also as they indicate habitat suitability and/or can be a proxy for other outcomes. Ruiz-Jaen and Aide (2005a) note that no restoration research published at that time measured all the attributes identified in the SER Primer (SER 2004) and encourage the use of at least two variables within each of the three SER ecosystem attributes that relate to ecosystem functioning.

Ecological monitoring procedures relevant for assessing ecological completion criteria are detailed in a number of recent books devoted to the subject (e.g. Likens & Lindenmayer 2018), as well as text books on restoration such as (Galatowitsch 2012). Many guidelines discuss monitoring approaches and issues in relation to mining rehabilitation, and the locally relevant documents are summarised in Table 3.9. The points that relate to sampling design constraints and specific to monitoring of rehabilitation and comparison with reference site data for completion criteria are addressed in the following sections.

TABLE 3.9 Key guidance documents for monitoring methods in relation to mining impacts and rehabilitation

Title	Reference	Comments
Evaluating performance: monitoring and auditing	LPSDP 2016b	Provides “Typical elements of a monitoring and performance program” including, what to monitor and how often, and example performance criteria. Does not include specifics of how to monitor but does provide guidance on criteria, and their relationship to monitoring. Gives examples of typical element of completion criteria, for landforms, water, biodiversity
Biodiversity management	LPSDP 2016a	Outlines key principles and procedures for assessing, managing, and monitoring biodiversity values, including monitoring and reporting on biodiversity management performance
Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Volume 1	ANZECC & ARMCANZ (2000a)	Volume 1: provides a management framework for applying the guidelines to natural and semi-natural marine and freshwater resources. It also provides a summary of the water and sediment quality guidelines to protect and manage environmental values supported by the water resources, as well as advice on designing and implementing monitoring and assessment programs Sections 1–7 contain the body of the guidelines and specifies trigger values for the protection of aquatic ecosystems and the numerical criteria for protection of other environmental values
Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Volume 2	ANZECC & ARMCANZ (2000b)	Volume 2 (Section 8) provides further guidance on protecting aquatic ecosystems, and describes water quality issues, modifying factors, decision trees, toxicant profiles and biological assessment
Review of methods for water quality assessment of temporary stream and lake systems	Smith *et al.* (2004b)	Provides a practical review and guidance for assessing the quality of temporary waters (using chemical and biological indicators). Of particular relevance for evaluating the impacts of mining in arid and semi-arid regions of Australia
Guidelines for Mining Proposals in Western Australia	DMP (2016)	Principles and purpose of monitoring are discussed for each criterion. Includes example tabular framework of: factor, objective, risk, outcomes, criteria and monitoring
Guidelines for Preparing Mine Closure Plans	DMP & EPA (2015)	Provides a planning process is in place so that the mine can be closed, decommissioned and rehabilitated to meet DMP and EPA’s objectives for rehabilitation and closure in Western Australia
Technical Guidance – Flora and vegetation surveys for environmental impact assessment	EPA (2016b)	Directed at planning and undertaking flora and vegetation surveys for environmental impact assessment (EIA)
Technical Guidance – Terrestrial fauna surveys	EPA (2016f)	Provides direction and information on general standards and protocols for terrestrial fauna surveys for EIA
Technical Guidance – Sampling methods for terrestrial vertebrate fauna	EPA (2016d)	Addresses survey design and sampling methods for terrestrial vertebrate fauna in the context of proposals where fauna is a relevant environmental factor
Technical Guidance – Subterranean fauna survey	EPA (2016e)	Addresses how subterranean fauna are considered in EIA in WA and provides advice to proponents on the level of information and survey required and how to analyse the results
Technical Guidance – Sampling methods for subterranean fauna	EPA (2016c)	Addresses survey design and sampling methods for subterranean fauna in the context of proposals where subterranean fauna is a relevant environmental factor
Soil Guide: a handbook for understanding and managing agricultural soils	Moore (2004)	Integrates assessment of soil properties, their influence on soil fertility and land degradation, and options for management or remediation
Global Acid Rock Drainage Guide	INAP (2009)	A summary of the best practices and technologies for prediction, prevention and management of acid rock drainage
Managing waste rock storage design – can we build a waste rock dump that works?	Barritt *et al.* (2016)	Overview of principle of appropriate design of waste rock landforms, with associated case study
Hazardous materials management	LPSDP 2016c	Addresses environmental issues associated with hazardous materials, such as minerals, process chemicals, dangerous goods, radioactive materials and wastes

3.7.2 Sampling independence

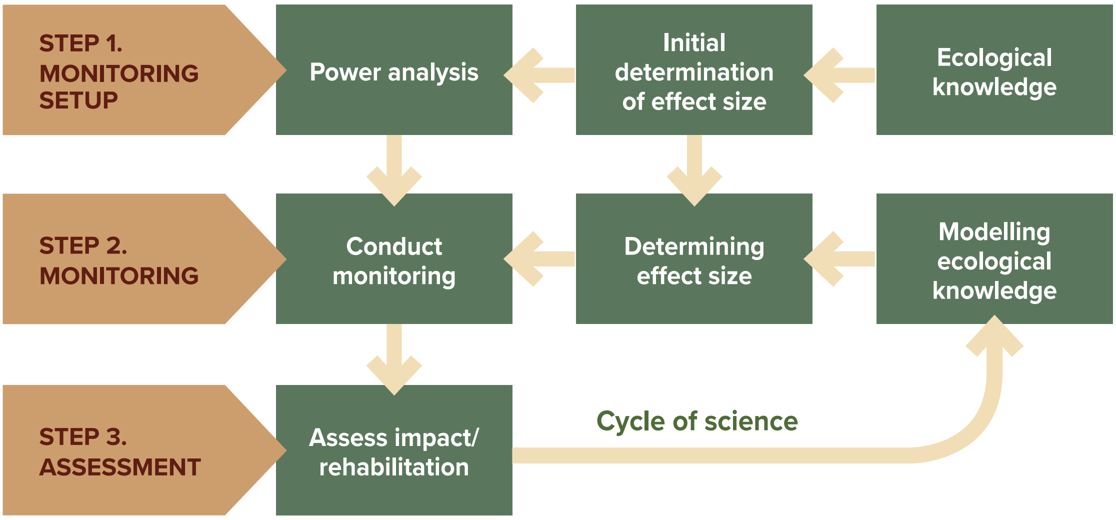
A fundamental principle of sampling design for statistical testing, but equally for other testing approaches, is that samples are representative and independent (Likens & Lindenmayer 2018). Representative means that samples (e.g. plots) are distributed in an unbiased way across the variation present in measured parameter in the sample area and capture a fair representation of that variance. Independent means both that plots are not all selected where outcomes are particularly good (e.g. places were weed cover is zero) or are not chosen to include sites with the highest and lowest values, but that the selection is neutral or independent in relation to the value being tested. Typically, this means randomly. If some factor is known to influence the parameter in question, such as year of rehabilitation, then these factors should be sampled and tested as separate groups. Sampling designs, such as random-sited systematic approaches, can make the logistics of a random design simpler, but still deliver an independent design, although sometimes at the expense of spatial representation.

Sampling independence is a particular issue for aquatic systems where, for example, in rivers all sites are interconnected and are essentially not-independent. It is advised that specialist advice is sought prior to development of monitoring for aquatic ecosystems.

Spatial autocorrelation and pseudo-replication are other issues of concern to ecological monitoring and in research. They relate to sample independence and inference. Spatial autocorrelation occurs when a feature of concern has a specific spatial pattern (such as seedling emergence in riplines but not intervening crests), and sampling is spaced at the same scale as the pattern. It is easily avoided with some consideration. Pseudo-replication is a problem for many ecological studies, and in a rehabilitation setting it may be particularly difficult to avoid. It occurs where all sampling replicates are placed in a single treatment or polygon for a given age and domain, rather than many. Multiple samples in just one treatment block allow assessment of that treatment block and it is wrong to assume it can be generalised to other blocks of the same treatment and capture representative variance of the year and domain. Ideal design would include multiple instances of the thing being tested, rather than multiple replicates within just one. This can be an issue in rehabilitation monitoring, but more often reporting only relates to the area monitored.

3.7.3 Statistical power

The critical importance of understanding and employing statistical power in mine rehabilitation monitoring for completion is emphasised by Lechner *et al.* (2012). Power is a measure of the confidence that a statistical sampling design is able to detect a difference of a given size if where such a difference exists. Low power arises when designs include few data points, or there is very high variance in the data and the effect size being tested is small. Effect size describes the minimum size of a difference that is being tested and it should be based on a consideration of what a meaningful difference would be. For instance, very intensive sampling would be required to be confident that a 1% difference in mature forest cover between a sample of reference plots and monitored rehabilitation sites could be statistically significant under normal standards (e.g. in an ANOVA with $p<0.05$). Most designs would not have adequate power to detect a difference at this effect size, but a trade-off exists between sampling intensity, power and minimum effect size. Instead, for this example, it might be important to know if a survey design could detect a 15% difference in vegetation cover, because that is a more ecologically relevant and meaningful difference. If a test finds a significant difference, then power is adequate, but if it does not, it may be that either there was no difference, or that the design was not powerful enough to find one that did exist. Power can be assessed prior to survey design, with some input knowledge of likely variation in data and a determination of the minimum effect size (see figure), or it can be assessed after the case. Assessing after the case does not help with design but does indicate whether the test is robust or not. Considering power draws attention to number of samples in a survey, the area (or accuracy) of samples (e.g. plots), the variance of the parameters and the effect size. Technical statistical advice is recommended for power analysis or consideration.



Source: Lechner et al. 2012

FIGURE 3.2 A model for incorporating effect size in monitoring design

3.7.4 Monitoring for diverse purposes

Monitoring is critical for completion criteria assessment but is also valuable for other purposes. For instance, both adaptive management and strategic research require monitoring to test specific treatments and support changes in approach to improve processes. Likewise, monitoring is useful to maintain ongoing awareness of areas that may require remediation or follow up action, or to track progress towards achieving completion criteria, prior to any point where regulatory assessment or reporting is required. Monitoring for these purposes could be designed on a different schedule, with different intensities and methods, and even to address metrics other than those required for completion criteria.

An important complement to monitoring for a mining operation is a commitment to retain detailed meta-data relating to each rehabilitated area including dates, site treatments, seed mixes, and climatic conditions.

3.7.5 Monitoring ecological attributes

Major categories of ecological attributes relate to flora and vegetation; fauna and fauna habitat; and ecosystem function and sustainability. Each of these have their challenges for monitoring and assessment.

Flora and vegetation

Flora and vegetation attributes address the structure and composition of vegetation. The composition of a community is the list of species, their identity and their relative abundance.

The most basic composition attribute is species richness which is a simple count of species present. Richness is often conflated with 'species diversity' which, in a technical sense, is a different measure. Diversity takes into account both richness, and the relative evenness of abundance of the species present (Hill 1973). It is rare that species evenness, and hence species diversity, would be used in completion criteria, simply because most of the importance associated with the concept of diversity is captured by richness alone, and evenness is rarely a key concern on its own in rehabilitation (Martin *et al.* 2005). Calculation of evenness and diversity requires a count of abundance for each species, whereas richness simply requires a count of species. When evenness is not of concern, use of the term 'richness', instead of 'diversity', will avoid causing confusion among ecologists.

Species richness, while a simple count, is not necessarily simple to compare between samples. This is due to a problem with scale, resulting from the species-area curve, or the species-accumulation curve. Essentially, as more individuals are counted (or accumulated) in a sample, more species may be found. This would be the case if all species occurred at the same abundance, but is exacerbated by the fact that many species are infrequent, and that most have patchy occurrences (Miller *et al.* 2016b). As a result, comparisons of reference site richness data with rehabilitation monitoring data require the measurements to be on the same basis. At a minimum, this means surveying the same number of samples each of the same area, but a further complication arises from changing density through time. Young rehabilitation sites may have many seedlings per m^2 and hence potentially many species. Through time, seedling numbers thin out and ultimately there may be few or no plants in a single m^2, which may also be the case in mature reference woodland vegetation, for instance (Figure 3.1). Thus, richness samples need to take into account both area and density, or number of plants surveyed. Rarefaction enables comparisons of richness among samples of different sizes (Gotelli & Colwell 2001). Approaches also exist which enable estimation of total richness for a given area from a set of samples within it, although these should be employed with some caution (Chiarucci *et al.* 2003). At a minimum, species richness should be reported as both mean number of species per plot and total number of species found in a sample of plots, given that the same species will not be found in each plot, for this reason richness should not be surveyed in unbounded relevés (Table 3.12).

In much of Western Australia, fire is a regular event in natural ecosystems and post-fire recovery results in many new individuals recruiting, often including new species which were not observed in the mature vegetation. These short-lived, or ephemeral plants, are part of the ecosystem and ideally should be assessed in reference state survey. Furthermore, these ephemeral species are useful in rehabilitation, helping to quickly establish cover after disturbance, and may assist with ameliorating the local environment for seedlings of longer lived species, including by adding soil carbon as they senesce and decompose (Miller *et al.* 2016a). The presence of these short-lived fire-responding species after fire, or in rehabilitation if transferred topsoils, add another element to boost richness and lead to longer-term changes following disturbance or rehabilitation (Gosper *et al.* 2012). Solutions to the complexity of incorporating successional changes in richness and density in completion criteria development and monitoring may require some local ecological understanding and careful thinking to move beyond comparison of young rehabilitation with mature phase reference vegetation (Matthews *et al.* 2009). The process of developing performance targets that reflect regeneration process following natural disturbance provides data and insights on timeframes for rehabilitation development (Kirkman *et al.* 2013).

Beyond a base measure of richness, community composition is infrequently quantified as a restoration target in itself – in spite of techniques for assessing ecological similarity or difference being well developed in community ecology and project goals often including expressions such as returning a similar vegetation community (Ruiz-Jaén & Aide 2005a; Koch & Hobbs 2007; Wortley *et al.* 2013; Miller *et al.* 2016a). If it is important that the same, or indeed a different, specific vegetation community is to be returned (such as if mining in a threatened ecological community or nature reserve), then it is reasonable that a completion criterion should require confirmation that the community returned is in fact the same as the target. Variation in community composition is measured through similarity (or dissimilarity) metrics (Ruiz-Jaén & Aide 2005a), which consider the relative similarity of the list of species that occur in pairs or groups of sites (with or without their varying abundance depending on the measure). Composition varies spatially in natural communities as a result of species patchiness and turnover, and between communities. In practice, not all communities are defined in this way, and no global standard for difference in similarity is accepted as definition of a change in community, but statistical tools such as ANOSIM, adonis, PERMANOVA and MANOVA can help to identify if two sets of vegetation samples differ in composition, while SIMPER (similarity percentages) and Indicator Species Analysis assist with identifying which species contribute to differences (Dufrene & Legendre 1997; McCune & Grace 2002)

A number of techniques for measuring vegetation cover are well known, and several new technologies are becoming increasingly important in this field.

TABLE 3.10 Comparison of methods for estimation of vegetation cover

Method	Variations	Strengths	Weakness	Outputs
Photopoint monitoring		• Simple to employ • Provides visual record useful for communication	• Site based and field intensive • Does not provide numeric data	• An image
Visual estimation	• Several estimation scales (Braun-Blanquet, Domin scale) and tools exist	• Simple to learn and employ • Appropriate for assessing gross changes • Can easily include vegetation structure, weed assessment and vegetation composition in the same survey • Technically simple	• Site based and field intensive • Prone to high error and low repeatability even among experienced users	• Estimated total cover for plot • Cover per species • Live and dead cover
Point or line intercepts	• Line or pole intercept approaches	• Simple to learn and employ • Repeatable and objective • Appropriate for assessing smaller differences in cover • Technically simple	• Site based and field intensive • Less well known and used • Time consuming	• Measured cover for plot • Cover per species • Live and dead cover • Structure
Remote sensing	• Image analysis • LiDAR • Aerial photogrammetry • Drone, plane or satellite platforms	• Able to assess broad areas rather than sampled points • Can often largely be implemented remotely • LiDAR able to provide vegetation structure data • With training can distinguish some distinct species in some settings (e.g. weeds) • Enables some assessment of change in condition or growth if repeated • Rapidly improving in capability	• Technologically intensive • Still experimental in some areas • Produces sometimes unwieldy volumes of data	• Total site cover • Can extract point cover • Size and shape of gaps and bare ground • Spatial patterns • Cover per species (for select species)

Remote sensing techniques are increasingly being employed to assess rehabilitation vegetation cover, and are considered effective at this task (Homolova *et al.* 2013; Atkinson 2018). Analysis of images from satellite, fixed-wing plane or drone-mounted sensors can detect the presence of vegetation or bare ground with remarkable spatial resolution. Issues with shadows, movement, image angle, time of year, varying atmospheric conditions and sensor status make comparison of repeated surveys challenging for specific points, but these issues can often be more manageable over larger areas. With sufficient returns per m^2, LiDAR (light detection and ranging) is effective for assessing vegetation structure and is increasingly able to traverse very large areas — the massive data associated with such efforts can be a challenge for management and analysis, but capability is increasing in this area also. Structure from motion or photogrammetric methods, requiring overlap of images from different angles, can be used to interpret surface (ground and canopy) heights and to classify vegetation and ground. Analysis in variation of values from multispectral sensors are frequently used to assess change in vegetation greenness or condition, with greenness measures such as Normalised Difference Vegetation Index (NDVI) being well known. Comparison of images from different seasons can pick up annual versus perennial (and hence sometimes weed cover) and total plant cover change through time. The application of techniques such as object-based image analysis to differentiate species has the potential to further extend the value of aerial imagery (Homolova *et al.* 2013; Whiteside *et al.* 2011). With appropriate ground truthing and validation, these data can be expected to be more accurate and robust than that gathered from on-ground monitoring alone. Extensive training, calibration and validation of multispectral, and especially of hyperspectral imagery, is increasingly being able to detect objects of different types in remotely sensed images. This artificial intelligence/machine learning training must be undertaken for specific regions, soil types and vegetation types, and for each species, if species detection is required. While species detection is a feasible future capability, it is unlikely to ever be able to replace on-ground botanical survey, but it would be valuable for broad structural change.

Fauna and fauna habitat

Unless a specific priority, such as where threatened species, habitat or ecological communities are impacted, fauna are not often included in completion criteria for a number of reasons, including those discussed in the previous section. Where fauna or habitat- focussed completion criteria are required, monitoring can be indirect focusing on resources and habitat availability for fauna, or direct, measuring fauna populations. Fauna monitoring protocols vary widely by species and groups, with some groups being particularly challenging to study, and low detection rates and mobility mean that specialised statistical approaches are often required.

Fauna also deliver key ecosystem functions, such as bioturbation, nutrient cycling, population regulation through predation and herbivory, pollination, dispersal and provide food resources for higher tropic orders. Monitoring for function is discussed below. Monitoring fauna as indicator groups for rehabilitation development and function has been examined by Majer and colleagues in a series of studies. Bisevac and Majer (1999a, b) compare monitoring effort for vascular plant species, amphibian species, reptile species, bird species, mammal species, arthropod orders and ant species in Kwongan shrublands. It was found that while field and processing times varied, information yield (number of taxa) was highest for plants and arthropods, and effort required (time) was of the same order for these groups but higher for vertebrates. Majer (1983) and Majer and Nichols (1998) demonstrated that ants are particularly amenable for monitoring, recording relatively high species per hour of effort. This result is broadly confirmed in an analysis of monitoring in Jarrah forest rehabilitation (Majer *et al.* 2007) where spiders, true bugs (Hemiptera) and beetles were also shown to be useful indicators.

Ecosystem function; resilience and self-sustaining capacity

Ecosystem function and functionality are diffuse concepts that address the effectiveness of sustaining processes in ecosystems. These high-order processes are made up of many interacting and contributing sub-processes (Table 3.11). While it is important that these functions are active and effective, their complexity makes them challenging as criteria for measuring success: the attributes often take longer to develop in rehabilitation than other criteria and are difficult to measure (Ruiz-Jaén & Aide 2005b). With the exception of those relating to regeneration capacity and resilience — the ability of systems to respond to perturbation (Standish *et al.* 2014) — many functions are best demonstrated by their outcomes (Table 3.11), if they can be summarised in a simple way. The key outcome is the support for the ecosystem, which can be measured by the cover and richness of vegetation and the richness and abundance of the fauna community. Resilience and regeneration capacity are sometimes only demonstrated when they are required, such as in response to events such as fire: if they are not present, then the system fails. As such, it is useful to measure by experimentally manipulating or testing in sample areas (Herath *et al.* 2009; Miller *et al.* 2016a).

TABLE 3.11 Outcomes, processes and elements comprising the concept of ecosystem function

Functional outcome	High-order ecosystem process	Component elements
Production of viable and genetically fit offspring in necessary quantities for population replacement	• Connectivity and gene flow	• Mating systems • Viable population size • Pollen viability • Pollinator presence and activity • Seed dispersal agents present and active • Landscape connectivity for fauna movement
Regulation and support for plants and macro fauna	• Plant – animal interactions; • Trophic interactions; • Inter and intra-specific interactions; • Substrate resource availability	• Herbivory • Food sources for higher trophic orders • Competition and facilitation • Plant physiological function
Soil development, health and function	• Nutrient cycling; • Plant nutrient acquisition; • Nitrogen fixing	• Mycorrhizal fungi • Decomposer community • Soil microbial community • Biological soil crusts • Scratching and digging animals • Soil compaction and physical strength
Dynamic responses to abiotic processes	• Responsiveness to environmental disturbance and variation; • Resilience; • Successional change; • Self-organisation of spatial pattern	• Seedbank development and persistence • Development of lignotubers • Disturbance events (e.g. fire, inundation, tree fall) within natural regimes • Immigration, colonisation
Stable and functional landscapes	• Natural erosion and deposition regimes; • Retention of soil moisture; • Hydrological flows	• Vegetation cover establishment • Soil carbon development • Rainfall infiltration and retention • Absence or natural seasonal cycling of hydrophobicity • Soil turnover by digging animals

Developing and established molecular techniques are increasingly being recognised and shown to be powerful tools for understanding cryptic biological patterns in diverse environments (Williams *et al.* 2014; Fernandes *et al.* 2018). Metabarcoding or eDNA analysis (analysis of DNA present in environmental samples) is capable of detecting patterns of abundance and change in biotic communities (Fernandes *et al.* 2018). In a rehabilitation context, this can be particularly useful for understanding the development and state of soil microbial or groundwater stygofauna communities or detecting the presence or population composition of cryptic fauna species in a landscape (e.g. Bilbies, Macrotis lagotis) (Fernandes *et al.* 2018). The molecular information derived from these analyses enables identification of taxa or individuals – if the identity of either is already recorded in a library of samples matched with vouchered confirmed reference collections of the species – or of operational taxonomic units (OTUs). Analysis of OTUs can provide useful indication of the richness and composition of samples, and their relation to reference samples, even though the identity of the species represented is unknown (Banning *et al.* 2011). Soil functional attributes are increasingly being measured in battery techniques which assess many functions simultaneously (Muñoz-Rojas *et al.* 2016b). Microbial assemblages determined from '16S DNA analysis' is challenging much of our understanding of the underlying microbial processes in aquatic ecosystems (such as in sulphate reduction) that may be important for rehabilitation or remediation (e.g. Green *et al.* 2017). Landscape Function Analysis (LFA) is a tool specifically designed to simplify assessment of soil function and facilitate monitoring of restoration state or trajectory in relation to a reference condition. LFA involves transect-based soil surface assessment, designed to provide indicators of soil stability, infiltration and nutrient cycling. Combined with vegetation, erosion and habitat complexity assessments (as Ecosystem Function Analysis; EFA) these tools have been widely applied within the Western Australian mining industry (Tongway & Hindley 2003). While simple to apply and retaining many adherents (Maestre & Puche 2009; Munro *et al.* 2012), LFA and EFA are increasingly being replaced by either direct functional measures such as soil carbon respiration, or measures of rehabilitation biotic outcomes alone as they become simpler and better known.

3.8 Designing ecological monitoring of rehabilitation in relation to risk

As noted in Section 3.3.3 above, rehabilitation risk can be derived from a combination of the importance of the values that are impacted or required to be replaced, and the challenges in achieving them (arising from lack of precedent or knowledge, lack of demonstrated capability or commitment, environmental constraints, exceptionally short or long time frames or other complexities; Table 3.5).

Completion criteria prioritisation and formulation should be based on risk assessment (Section 2.7.2). The subsequent design of monitoring programs to assess criteria should be tailored to reflect the specific formulation and expression of criteria. This can be an iterative process: it is advisable to consider potential monitoring approaches to some extent when formulating criteria. Completion criteria may not all represent attributes considered to be high risk, and sometimes risk may be recognised as varying across rehabilitation domains. Even though attributes may be considered lower risk, sometimes there may be a need for monitoring, whether as part of completion criteria or for other purposes. Monitoring lower risk attributes or locations may not require the same evidence, design, monitoring intensity or standard of testing as high-risk attributes or sites. The table on the following pages lists the most common ecological attributes monitored, together with standard approaches appropriate for varying levels of risk (Table 3.12).

Photo courtesy: Alcoa

TABLE 3.12 Ecological parameters useful or used in completion criteria development with monitoring approaches

Monitoring approaches are suggested as appropriate for varying levels of failure risk. A plus sign (+) indicates that requirements are additive from the previous column. Basic statistical tests and other useful tools appropriate for demonstrating success are shown with shading to indicate the minimum level of risk to which they should be applied. Higher risk approaches can be applied at lower levels if feasible and efficient.

	Low risk	Moderate risk	High risk	Statistical test / Other tools	Relationships with other measures
FLORA AND VEGETATION					
Plant community species richness	Mean species richness within plots	+ total richness in survey (area corrected in some form)	+ rarefied species counts adjusted for number of individuals and or plots; adjust for successional trajectory	t – test ANOVA Species-area or accumulation curves for visualisation	Stand-alone top-level measure
Diversity					A specific reason required to do this and not just Richness
Vegetation composition	Confirm all species in seeding and topsoil source are from local community	Confirm all species in rehabilitation are from the target community; ensure framework taxa are present	+ assess similarity and differences relative to reference; ensure indicator species are present	Adonis, ANOSIM Classification; Ordination (NMDS, PCA)	Stand-alone, top-level measure
Functional types	Ensure mix of life forms are used in seed mix or present in rehabilitation	+ ensure mix of successional stages / life span are used in seed mix or present in rehabilitation	+ asses presence and relative abundance of agreed functional types (consider pollination syndromes, flowering times, seed types, storage modes)	Adonis, ANOSIM Classification; Ordination (NMDS, PCA)	Supplements composition, as an additional measure for high standard projects, or could replace it if a lower standard acceptable
Provenance	Propagules should be regionally sourced	Apply agreed collection zone – e.g. distance and/or bioregion	Assess provenance zones or collect only from local (on site/ adjacent) sources		Stand-alone, but rarely a criterion, more often a required part of process
Vegetation cover	Photopoint comparison	Visual estimation (eg Braun-Blanquet or Domin scale)	Quantify intercepts on points or transects, or; use remote sensing	t – test ANOVA Analyse gap or patch size distributions, variance in cover	Often a stand-alone measure, but could be replaced by density or structure
Vegetation structure	Photopoint comparison	Apply physiognomic classification rules	Assess/estimate cover in strata		Supplements Cover, as an additional measure for high standard projects, or could replace it if a lower standard acceptable

Table 3.12 continues following page...

TABLE 3.12 Published guidelines relating to mine closure and or completion criteria

	Low risk	Moderate risk	High risk	Statistical test Other tools	Relationships with other measures
Stem density	Counts in plots, transects or PCQ		+ compare with reference successional (e.g. post-fire) trajectory	t – test ANOVA	Rarely more effective than Cover unless a specific tree species density is required
Weed abundance	Presence of non-native species	Estimated or measured cover in plots, or survey of density; remote sensing if effective	+ map weed distribution	t – test ANOVA	Stand-alone as required
FAUNA AND FAUNA HABITAT					
Non-specific fauna	List resident, breeding, visitor observations	Survey key groups for occurrence	Assess presence or abundance of indicator species/ guilds	ANOVA Ordination PERMANOVA ANOSIM	Assessed for highest standard projects
Specific fauna (if required)	Appropriate habitat or resources	Record of presence	Appropriate quantitative approach; camera traps; pitfall survey; radio tracking	ANOVA	Stand-alone as required
Fauna habitat	As per vegetation cover (low or medium)	+ as per vegetation structure (high), + presence of food sources	+ survey density and quality of specific elements – nest hollows, roost trees, food sources	ANOVA	Assessed for high standard projects; complemented by vegetation cover and/or structure
Other biota		Presence of major fungal guilds	+eDNA analysis for soil biota	PERMANOVA ANOSIM Classification; Ordination (NMDS, PCA)	Assessed for highest standard projects, can be used with, or instead of, ecological function

Table 3.12 continues following page...

TABLE 3.12 Published guidelines relating to mine closure and or completion criteria

	Low risk	Moderate risk	High risk	Statistical test / Other tools	Relationships with other measures
ECOSYSTEM FUNCTION AND SUSTAINABILITY					
Resilience	Evidence of flowering and seed production	Evidence of seedbank viability (seedbank audit) and/ or recruitment	Test by experimentally imposing disturbance – assessing a set of other measures (cover, composition, weeds etc.	ANOVA Ordination	Important but difficult to assess properly; best associated with on-site research. Overlap with 'self-sustaining', and may employ others for assessment
Ecological function	Subjective 'condition' assessment	Compare plant growth and survival rates with reference at same stage	Soil microbial Function tests; compare plant ecophysiological performance	ANOVA	Similar to 'self-sustaining'
Landscape function	Assess largest bare ground gap area	Compare quantified bare ground with reference	Measure infiltration; soil transpiration; survey erosion	ANOVA	Can be complemented by ecophysiological performance (Ecological function). May be redundant if vegetation cover and structure developing as required
Connectivity or landscape integration	Physical connectivity as planned	+ assess hydrological connectivity	+ radio tracking for fauna; paternity assessment for pollen flow	ANOVA Relevant tests	Stand-alone
'Self-sustaining'	Evidence of, growth, survival, flowering and seed production	Recruitment or seedbanks demonstrated in field; Ecophysiological performance at least equal to reference for similar stage	Several generations observed at stand replacement level; demographic modelling	PVA	Similar to resilience and also difficult to demonstrate, may be addressed through mix of resilience and ecological function measures
Specific ecosystem service	Presence of features supporting service delivery	Quantify abundance of feature providing the service delivery	Social or economic analysis of value of services provided	As appropriate	This form of completion criteria is more appropriately considered among social or economic attributes, but its monitoring may include biological elements, such as in bioremediation by wetlands, honey production or carbon storage

4
CHAPTER

4 Stakeholder interviews and industry survey

4.1 Introduction

The stakeholder consultation component of this project consisted of two main phases:

1. Stakeholder interviews
2. Industry-wide survey.

These consultation phases were targeted at three broad groups of stakeholders: environmental managers or compliance officers within mining companies, consultants engaged with developing mine closure plans and completion criteria and regulators with experience in assessing mine closure plans or mine completion processes.

The first phase (stakeholder interviews) aimed to understand current industry practices and identify key issues of concern, existing gaps and potential solutions to the development of mine closure criteria in Western Australia. The interview results provided input for development of a wider stakeholder survey (phase two). In this chapter, we describe the interview and survey methodology and present the results of both.

4.2 Methods

4.2.1 Stakeholder interviews

Interviews were conducted with a range of relevant stakeholders sourced from the Project Industry Advisory Group and word-of-mouth recommendations. The interviews followed a standard methodology referred to as the 'general interview guide' (Daniel 2010). This consists of semi structured questions which allow a high degree of flexibility for the interviewer to adapt questions based on the participants' responses. The indicative interview guide consisted of four parts:

1 Decisions about post-mine land use;
2 How are completion criteria currently defined (including attributes and references used);
3 Risk assessment and monitoring practices;
4 The process of mine closure planning in Western Australia (including coordination with regulators and resource availability).

The open-ended nature of the questions can prompt participants to provide narrative, descriptive answers. The main advantage of this method for our specific research purpose is that it allowed interviewees to provide new insights into the topic, which may not have been previously mapped by the researchers.

Potential interviewees were invited via email and, if agreeing to an interview, a suitable date and time was identified with the lead researchers. Human Ethics approval was provided by the University of Western Australia's Human Research Ethics Office (RA/4/20/4241). Approximately half of the interviews were conducted with two researchers present. However, due to planning constraints, it was not possible for both researchers to be available for all interviews. If consent was provided by the interviewee, the interview was recorded. All interviews were transcribed and reviewed by both researchers after completion.

Photo courtesy: DWER

The aim of the interviews was to understand stakeholders' perspectives in relation to current practices for developing completion criteria. In particular, the objective was to identify existing issues which the framework would try to address; as well as positive experiences that would serve to inform the framework's content. Qualitative answers were systematically analysed employing the SWOT method, which evaluates Strengths, Weaknesses, Opportunities, and Threats associated with the question of study (Jackson *et al.* 2003; Pickton & Wright 1998). These four dimensions served to analyse an organisation's internal and external environments, as well as identify positive and negative impact factors (Source: Adapted from Yüksel and Dagˇdeviren (2007) Figure 4.1).

		IMPACT	
		Positive	**Negative**
ORIGIN	**Internal**	Strength	Weakness
	External	Opportunity	Threat

Source: Adapted from Yüksel and Dagˇdeviren (2007)

FIGURE 4.1 SWOT analysis diagram

4.2.2 Industry survey

Respondents to the wider stakeholder survey were identified through professional networks of the project staff, word-of-mouth and from publicly available information such as company websites, mine closure reports (e.g. authors of mine closure plans, and published literature such as Mine Closure Conference proceedings). Each stakeholder group received similar questions (multiple choice and open answer questions) addressing the topics listed below. Because some questions were phrased differently for different stakeholders, and depending on a respondent's answers to previous questions (and subsequent skip logic), the number of questions shown to respondents in each section varied:

- Screening to ensure respondents met the selection criteria i.e. being involved in developing, advising on or approving mine completion criteria and/or closure plans (4 questions);
- Stakeholder organisation, such as mining business, consultancy firm, or regulatory body. Also questions about predominant minerals mined or consulted for, and approximate company size (2–3 questions);
- Completion criteria: Industry members were asked to base their responses on a specific site they had worked at, while consultants and regulators were asked to answer the questions for the majority of closure plans developed or reviewed (10–16 questions);
- Monitoring and evaluating progress towards completion criteria, such as the references and methods that are typically used (3–9 questions);
- Coordination within the organisation and engagement with other organisations (4–6 questions);
- The final section asked about available resources for the development of completion criteria and invited respondents to submit any additional comments (4–6 questions).

The survey was programmed in the Qualtrics survey software. Potential respondents were invited via email through an anonymous survey link. The initial survey invitation was sent to 100 valid email addresses. Respondents were asked to distribute the link to other members of their team(s) involved in mine closure or in developing mine completion criteria. Because the software system does not keep count of forwarded surveys (only those completed), we cannot identify precise survey response rates. A total of 75 completed surveys were returned, which is indicative of experts' willingness to contribute to this research and the perceived importance of the topic.

4.3 Results

4.3.1 Interview results

Between February and May 2018, 17 interviews were conducted with regulators (4), consultants (5), and mining companies (8). Some organisations had more than one person taking part in the interviews, which resulted in a total of 26 stakeholders being interviewed.

For each of the 17 organisations interviewed, key strengths, weaknesses, opportunities and threats were identified (Source: Adapted from Yüksel and Dagˇdeviren (2007) Figure 4.1 above). A large number of *threats* were identified, as participants more often articulated negative external factors, rather than internal limitations. However, a few organisations also described their *weaknesses* which, in some cases, coincided with *threats* identified by others (e.g. lack of coordination between teams within the same organisation). During the data analysis, it became apparent that certain issues recurrently appeared across several interviews. Interestingly, such commonality in responses highlighted several key points of agreement across regulators, consultants and mining companies.

The narrative responses were synthesised into groups of information representing common ideas — an approach known as thematic analysis (Boyatzis 1998). While there is no formal restriction on the number of themes, Creswell (2013) and Lichtman (2012) indicate that qualitative information should typically be categorised into five to seven main concepts. In our study, six key themes were identified: end land use; coordination; completion criteria; monitoring; capacity; and processes. Each of these key themes comprised several sub themes on particular issues (Table 4.1). Most commonly mentioned was the disconnect and disagreement among various Government departments. This issue is clearly illustrated by the experience shared by one mining company:

> *"For our mines operating on Crown Land, approval from DMIRS is needed. DMIRS will liaise with other departments, such as EPA, DBCA, Water, Housing, DPLH, Local Government Authorities (LGAs), among others. In one of our sites, contradicting demands from different departments resulted in a Mexican standoff between LGAs, DPLH, and DBCA. There are too many agencies we have to interact with, they all have their own ideas and agenda."*

The other common highlighted issues were: the lack of government capacity; lack of incentives for companies; liability associated with 'alternative' post-mining land uses; and a too narrow focus on ecological, numerical targets. As one industry proponent explained "Completion criteria are very environmentally focussed, which creates a contradiction between EPA (prioritising ecosystem restoration) and DMIRS (focusing on 'safe, stable and non-polluting')." A consultant also noted that "Completion criteria are typically written by environmental consultants — not land planners, which is why mine closure plans are limited in scope".

Other important challenges identified by interviewees were inconsistencies between teams within the same stakeholder group (both within companies and between government departments) and contradictions in preferred post-mining land use between stakeholders and regulators.

Several interviewees identified positive aspects (summarised in Table 4.2). Each of the eight mining companies, as well as one regulator and one consultant, praised their internal knowledge and practices as key strengths. For example, one representative of a mining company explained that "Our rehabilitation uses best practices to optimise outcomes, so we are able to meet our completion criteria". Another company noted that "As our mine sites are relatively new, we are able to do things right from the start. We have enough internal resources, as well as an education program about the importance of rehabilitation".

The second most commonly mentioned positive aspect was the regulators' recent and gradual shift in mindset, chiefly regarding the acceptance of different PMLUs and reference sites. As one mining proponent explained "Increasingly, it is being recognised that expectations for pre-mining uses are unrealistic".

Other positive messages included the benefits obtained from knowledge sharing between mining companies and the substantial monitoring improvements offered by emerging technologies (e.g. drones). Contrary to expectations about government resources, one consultant and one mining company notes that the regulators' level of knowledge and advice were adequate for industry to develop completion criteria. In the words of one interviewee, "There is enough guidance from the regulator — more would be too prescriptive".

TABLE 4.1 Common themes, weaknesses, and threats identified though thematic analysis of interview data

Common themes	Weaknesses and threats	Times mentioned (n=17)
Post-mining land use (PMLU)	Limited consideration of PMLU, other than reverting to pre-mining land use	4
	Lack of guidelines on how to select PMLU	1
	Contradiction of preferred PMLU between regulators and stakeholders	6
	Lack of consultation with land planning	2
Coordination	Disconnection between approvals team (early stages of mine closure planning) and completion/rehabilitation team (final stages of mine closure planning)	7
	Disconnection and disagreements among various Government departments	11
	Inconsistent guidance given by regulators over time and across staff members	6
	Limited knowledge sharing among mining companies	2
Completion criteria	Rehabilitating to "what was there before" is ecologically impossible and financially infeasible	4
	Lack of guidance to define SMART[1] criteria and criteria for 'self-sustaining ecosystem'	4
	Benchmarking against analogue sites is unrealistic, particularly for hard-rock mining	4
	Too narrow focus on numerical targets and ecological aspects, with little consideration for overall rehabilitation success or safe, stable, non-polluting aspects	8
	Risk should be incorporated in development of completion criteria (and monitoring)	3
	No policy on rehabilitation	4
Monitoring	Lack in monitoring guidelines (particularly on new technologies) and limited monitoring consistency	5
	Monitoring is often untargeted and not matched against completion criteria	2
	Monitoring should be time-bound	3
Capacity	Competency gap within the Government to assess various closure aspects (engineering, safety, pollution, biodiversity, community, long-term planning etc.)	8
	Lack of incentives for companies to invest in closure planning and achieve high rehabilitation outcomes	8
Processes	Residual risk (liability) linked to alternative land uses is a main impediment to relinquishment/alternative land uses	8
	Important differences between older (previously mined) and new sites; shallow and hard-rock mining; big and small companies; under Mining Act and under State/ Ministerial Agreements	5

[1] Specific, Measurable, Achievable, Relevant and Time-bound

TABLE 4.2 Common strengths and opportunities identified though thematic analysis of interview data

Strengths and opportunities	Times mentioned
Good internal knowledge and practices	10
Regulators are becoming more open to new ideas, e.g. alternate PMLU	5
Advances in technology help monitoring	2
Knowledge sharing among mining companies	2
The regulator's level of knowledge and guidance provided are adequate	2

4.3.2 Survey results

The industry survey was completed by 75 respondents, of which the majority (55%) were mining industry employees, and the rest were either consultants in the field or government employees involved with mine closure, mine rehabilitation, or completion criteria (Table 4.3).

TABLE 4.3 Number of survey respondents by stakeholder group

Stakeholder group	Number of respondents
Mining industry	41 (55%)
Consulting business	18 (24%)
Government agency	16 (21%)
Total respondents	**75**

4.3.3 Sample characteristics

Of the mining industry members, the majority were involved in iron ore, gold or basic raw materials operations (Figure 4.2), with operations spread across all regions of Western Australia. Company operating revenues ranged from less than A$1 million (three respondents) to more than A$5 billion in the 2016-17 financial year (nine respondents). On average, the operating revenue of responding companies was between one and five billion (Appendix 4.5.1).

The majority of the consulting businesses surveyed advised for gold mines, iron ore or mineral sand miners (Figure 4.2). Consulting businesses of different sizes were surveyed, ranging from sole traders (22%), small local businesses (45%), to large international companies (28%).

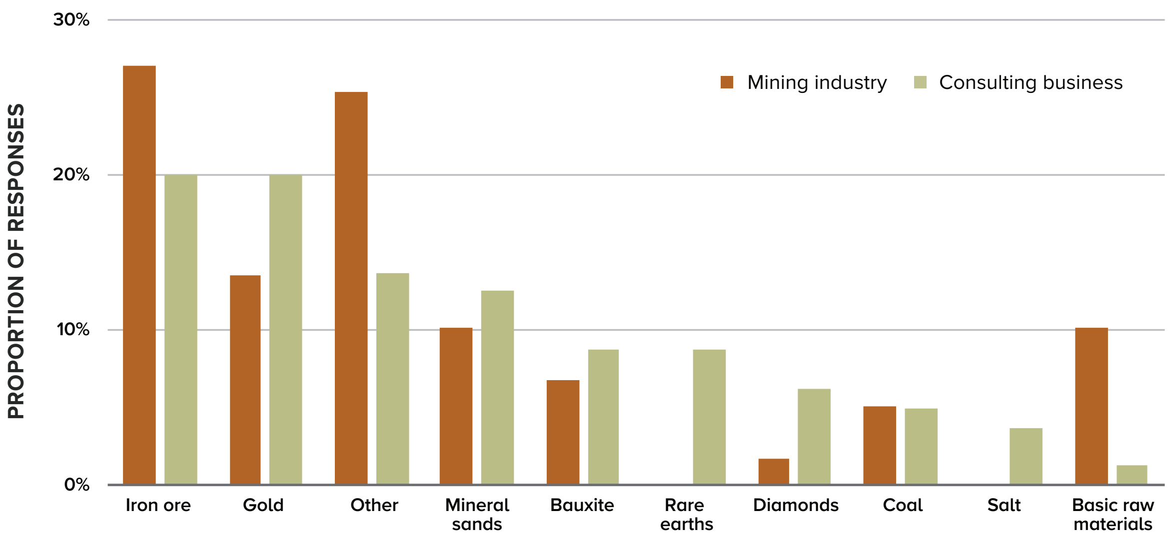


FIGURE 4.2 Main minerals and raw materials represented in stakeholder survey

Respondents from government agencies (henceforth ‘regulators’) came from the Department of Biodiversity, Conservation and Attractions (DBCA; six respondents); Department of Mines, Industry Regulation and Safety (DMIRS; three respondents); Department of Water and Environmental Regulation (DWER; three respondents); and the Department of Planning, Lands and Heritage (DPLH; two respondents). Two regulators did not state which agency they were affiliated with.

Industry members were asked to think about a specific mine site when completing the questions about completion criteria. The majority of the selected sites (73%) are currently in operation, including four sites under post-closure management. Selected sites are located on land that was previously tenured under pastoral leases, unallocated crown land, private land or native title (Table 4.4). Correspondingly, pre-mining land use was predominantly pastoral or natural ecosystem. The anticipated post-mining land uses were also predominantly pastoral and natural ecosystem/conservation (Table 4.4).

TABLE 4.4 Tenure, pre-mining land use and post-mining land use of the sites considered by survey respondents when completing questions about completion criteria

	Tenure prior to mine lease
Pastoral lease	35.7%
Unallocated crown land	25.7%
Private land	12.9%
Native title	11.4%
Forestry reserves	8.6%
Reserve land	5.7%

	Pre-mining land use	Post-mining land use
Pastoral	44.6%	34.7%
Natural ecosystem	30.4%	26.4%
Forestry	10.7%	5.6%
Agriculture	8.9%	8.3%
Recreation	1.8%	8.3%
Industrial or commercial	–	5.6%
Energy generation	–	2.8%
Other	3.6%	8.3%

4.3.4 Post-mining land use decisions

Both industry and consultants were asked how they typically determine post-mining land uses. For mining industry employees, post-mining land uses are typically determined through negotiations with local communities or regulators (13% and 27% respectively), or are based on what was there before (37%) (Figure 4.3). Five respondents (7.5%) stated that they use landscape capability assessments, and eight respondents (12%) use multi-criteria analysis to decide on post-mining land use at their selected site.

For consultants, post-mining land uses are mostly negotiated with the regulator, client or local communities (19%, 19% and 16% respectively). Seven respondents (11%) stated that they use landscape capability assessments, while multi-criteria analysis is used by five respondents (8%).

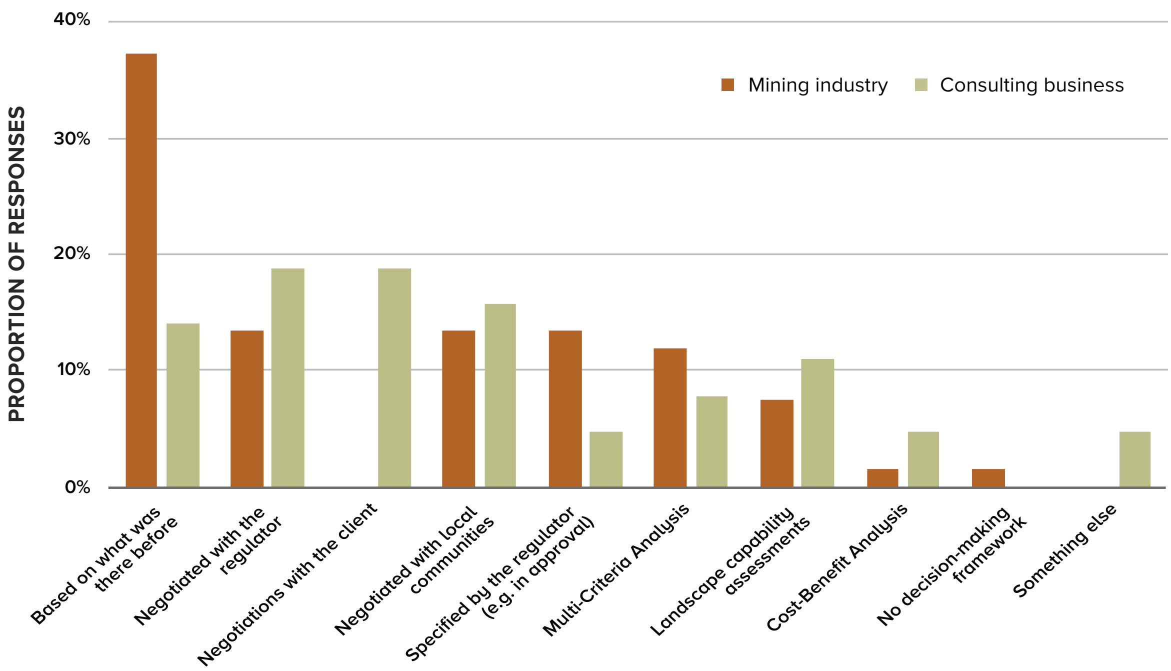


FIGURE 4.3 Decision processes used by survey respondents to determine post-mining land use

4.3.5 Developing completion criteria

Industry members and consultants use similar information sources to guide the development of completion criteria. The most often mentioned guidelines were the Department of Mines and Petroleum's (now DMIRS) *Guidelines for Preparing Mine Closure Plans* (DMP & EPA 2015), followed by various sources of knowledge internal to the own organisation or closure plans from other companies (Table 4.5). Only a minority of respondents use other guiding documents from Government bodies and independent expert organisations (EPA 2006a, 2016f; LPSDP 2016a, 2016b; SERA 2017).

TABLE 4.5 Information source(s) used by survey respondents to guide the development of completion criteria

What information source(s) do you use to guide the development of completion criteria? (tick as many as apply)	Mining industry		Consulting	
	% of resp.	# of resp.	% of resp.	# of resp.
Guidelines for Preparing Mine Closure Plans (DMP & EPA 2015)	19%	31	16%	16
Our rehabilitation team's knowledge	16%	26	14%	14
Our previous closure plans	15%	24	12%	12
Internal guidelines	10%	17	4%	4
Closure plans from others	9%	14	5%	5
Our approvals team's knowledge	7%	12	9%	9
Mine Closure Leading Practice Handbook (LPSDP 2016a)	5%	8	8%	8
EPA Environmental Factor Guidelines (EPA 2016a)	4%	7	8%	8
Mine Rehabilitation Leading Practice Handbook (LPSDP 2006e)	4%	7	7%	7
EPA Guidance “Rehabilitation of Terrestrial Ecosystems” (EPA 2006)	4%	6	7%	7
SERA Standards for Ecological Restoration (SERA 2017)	1%	1	5%	5
Other	6%	9	4%	4
Don't know	1%	1	0%	0
Total number of responses	**100%**	**163**	**100%**	**99**

An open question was used to assess how industry and consultants make sure that completion criteria are SMART (specific, measurable, achievable, relevant, time-bound). Most of respondents explained that they aimed to base completion criteria on measurable/quantifiable variables, with a reference/target specified. Such measurable attributes are typically:

- Determined through an iterative process where completion criteria are reviewed by the proponent, consultant and/or regulator before agreement is reached;
- Based on company's experience; or
- Based on monitoring data and available scientific evidence.

For example, one respondent stated that that they *“develop an indicative monitoring program to ensure all aspects can be measured and have a defined end point”*, while another respondent aimed to base completion criteria *“around factors that can be measured”*. Respondents provided multiple examples of measurable attributes used to assess progress towards completion criteria (Table 4.6).

Note that some indicators were expressed in a qualitative manner (e.g. ‘vegetation is sustainable'), which are typically more difficult to measure than indicators with quantitative metrics. Nevertheless, some respondents explained how they define qualitative attributes with measurable metrics. Take, for example, the completion criterion ‘number of key plant species is within the historically observed reference range'. This respondent defines ‘key plant species' as those species that have 80th percentile dominance by total coverage or individual plant count in vegetation units as defined by the relevant flora survey. ‘Reference range' is defined with respect to individual key plant species as plants per hectare by monitoring reference sites quadrats or comparative photo-points over time.

TABLE 4.6 Examples of metrics used to assess progress towards completion criteria provided by survey respondents

1. Example attributes with measurable / quantitative metrics

- Percentage (%) vegetation cover in rehabilitation areas
- Percentage (%) native perennial vegetation cover
- Percentage (%) species representation, relative to analogue sites or surrounding, unmined, areas
- Species diversity (total no. perennial species) at ≥50% of the mean value from the analogue sites in the target ecosystem
- Species density (total no. perennial plants) at ≥50% of the mean value from the analogue sites in the target ecosystem
- Density of native (non-legume) plant species (number/m^2)
- Density of leguminous understorey species (species/m^2) as measured approx. 1 year after rehabilitation establishment
- Minimum (and maximum) density of trees (stems/ha)
- Average weed foliage cover (%) is no more than 2% as compared with forest control plots
- Weeds shall compromise less than 5% of revegetated areas
- No areas greater than 0.1 hectare with less than 1 native plants per m^2 as measured approx. 2 and 10 years after rehabilitation
- Gully width and depth (m)
- Level of erosion (using AER erosion severity class scale, max. 2 or 3)
- Average erosion rates are below x t/ha.yr
- Absence of active gully erosion measured using either ground-based photography or aerial imagery
- No visible sediment deposition beyond containment structures
- Water quality in streams at a minimum level (concentration TSS, N, P) for three consecutive years after remove of mechanical intervention
- Mean LFA infiltration and nutrient cycling rating of ≥50% of the value of the analogue sites in the target ecosystem over three consecutive monitoring periods (for annual monitoring) or two consecutive monitoring periods (for biennial monitoring)
- LFA stability of rehabilitated waste rock landform achieves or exceeds an overall slope stability safety factor of 1.5
- Mean LFA nutrient and infiltration levels achieved are 70% of those of similar analogue environments in the surrounding region

2. Example attributes with qualitative metrics

- Future land owners'/community's level of acceptance of post-mining land use
- Landforms are safe and stable
- Landform design is compatible with agreed future land use
- Using EFA to identify the point of inflection where performance is moving towards sustainability
- Vegetation is sustainable and resilient to likely impacts such as drought, fire and grazing
- Recruitment of native perennial species is occurring or is likely to occur on the site
- Perennial plant cover in rehabilitated areas reach x% of the best achievable on the site
- Weed cover is less than long-lived perennial plant cover

Several mining industry respondents emphasised that their current completion criteria may still be broadly indicative criteria that are not yet SMART. Such completion criteria will be refined as more information becomes available leading up to closure. Three respondents noted that, because of this, time-bound criteria are not always possible or relevant. Having a time-bound criterion suggests that there is a limited time frame to achieve completion, which is not realistic with rehabilitation as an ongoing process.

Similar to results obtained in the interviews, it was suggested that criteria should be more process rather than outcome based, because it is uncertain whether defined outcomes can be attained. 'Process-based' completion criteria are those that focus on rehabilitation practices or inputs, rather than final outcomes. This has a parallel in the construction of leading versus lagging indicators (Section 3.6). For instance, setting a standard for way the site is prepared to provide the conditions required for restoration/rehabilitation, such as building fauna habitat, would be a process-based criterion, as opposed to fauna count, which is an outcome-based indicator. Similarly, interviewees expressed an interest in having completion criteria set in a time-bound manner, whereby targeted levels of performance (e.g. indices of vegetation development) would be set along a trajectory towards the agreed closure outcome.

Interestingly, about one third of regulators stated that the majority of mine closure plans lack detailed completion criteria, and more than half of regulators said that most plans do not contain measurable indicators. Government respondents stressed that the level of detail in completion criteria and indicators varies greatly between sites and companies (Table 4.7 or Figure 4.4).

TABLE 4.7 Respondents' answers related to mine closure plans details and indicators

	In general, are the completion criteria in mine closure plans sufficiently detailed and site specific?		In general, do the completion criteria in mine closure plans have measurable indicators against each criterion?	
	% of resp.	# of resp.	% of resp.	# of resp.
The majority of the plans I see have detailed and specific CC/measurable indicators	0%	0	7%	1
This varies greatly between sites	13%	2	7%	1
This varies greatly between companies	53%	8	29%	4
The majority of the plans I see lack detail in their CC/measurable indicators	33%	5	57%	8
Total number of answers provided	**100%**	**15**	**100%**	**14**

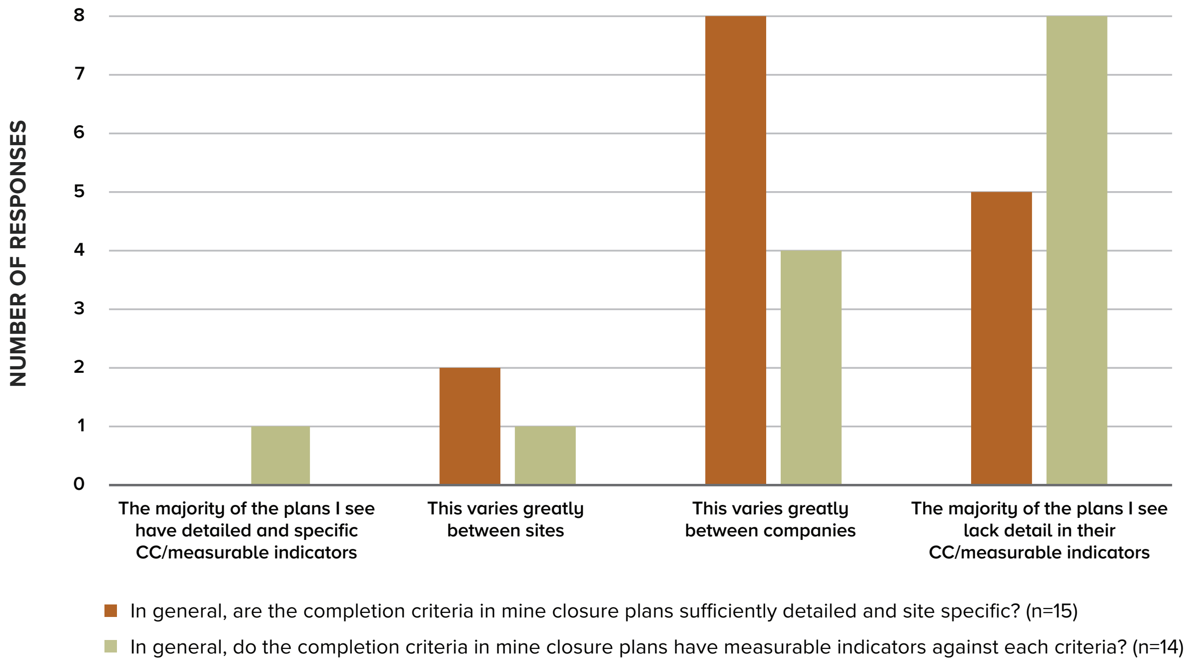


FIGURE 4.4 Level of detail provided in mine closure plans (number of responses by regulators)

The issue of achievability was raised by all three stakeholder groups. Eight industry and consulting respondents emphasised the difficulty in defining achievable criteria, because of the gaps in knowing what ecological restoration is feasibly achievable in Western Australia. For example, one industry respondent stated that "Current criteria were written during approval phase and do not meet SMART criteria, and are in their current form unachievable". Another respondent pointed at the difficulties of defining closure criteria for historical disturbance where baseline studies are absent.

Out of 15 regulator respondents, 14 agreed that, in general, completion criteria defined in mine closure plans are not achievable. This is mostly because (a) closure plans are still 'under development'; (b) completion objectives are generally non-specific without providing auditable detail. Consistent with the interview results, one respondent commented that "Completion criteria are usually written to make sure they can be complied with but are too ambiguous for accountability. They are designed to get approval for the development of the closure plan from regulators rather than to satisfy the land manager".

All three stakeholder groups (mining industry, consultants and regulators) answered a question about the major challenges encountered when developing or assessing completion criteria. Respondents were shown eight potential challenges, which they ranked from 1 (most important) to 8 (least important).

As shown in Figure 4.5, the most important challenge for all stakeholder groups is the lack in data to develop evidence-based completion criteria. This is consistent with other comments in the survey, where respondents noted that there is still insufficient knowledge about rehabilitation and ecological restoration in Western Australia. Feedback from participants indicated that more guidance on how to set appropriate and realistic completion criteria that are agreed amongst stakeholders is needed to help further the industry.

Student t-tests were used to test for differences between stakeholders and between mining businesses of different sizes. These tests showed that there were some statistically significant differences in assessments between stakeholders. "Government departments all set different standards" and "The regulator imposes additional standards on previously approved criteria" are significantly more important to mining industry than to the other two stakeholder groups ($p<0.05$). "We have no appropriate reference to benchmark achievement against" is significantly more important to regulators than to the other stakeholders ($p<0.05$). Another important challenge to consultants and regulators is "Alternative post-mining land uses are not adequately explored" (no significant difference).

We also tested whether differently sized mining and consultancy businesses placed more or less importance on the challenges listed in the survey question. The only statistically significant difference between companies is the higher importance placed by small mining companies (less than $100 million operating revenue) on "The regulator imposes additional standards on previously approved completion criteria" compared to mid-size ($p=0.06$) and large mining companies ($p=0.013$).

Photo courtesy: DWER

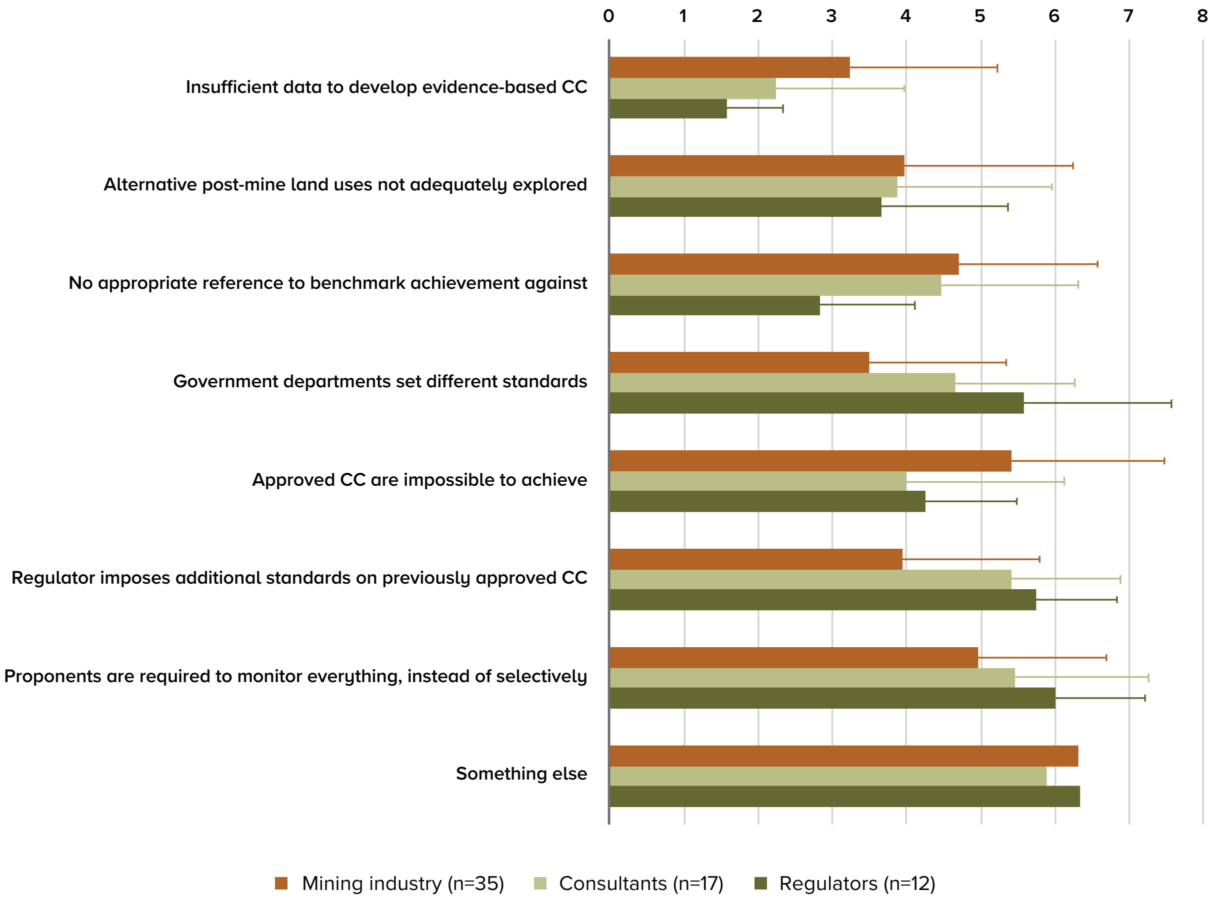


FIGURE 4.5 Challenges when developing completion criteria
Mean estimate for each stakeholder groups; **1** = most important, **8** = least important;
Error bars show standard deviations

4.3.6 Risks

An open question to mining industry respondents was about the most important ramification of not meeting current completion criteria. Answers included: an inability to relinquish tenure and liability (mentioned by 11/31 mining respondents); financial implications of costly remedial works (mentioned by 11/31 mining respondents); and reputational risks to a firm's social licence to operate (mentioned by 10/31 mining respondents). Four respondents explicitly stated minimising environmental and safety risks as a primary goal of rehabilitation, and that not meeting those criteria can reduce stakeholder support affecting future regulatory approval.

The main risks taken into account are very similar across all three stakeholder groups. Most important are financial risks, erosion, failure to establish vegetation, and ground or surface water impacts (Table 4.8). Community preferences, litigation and cumulative risks were mentioned least often. There are some variations between responses by the regulators and the other two stakeholder groups: acid drainage, climate change and cumulative risks are more important to regulators than to mining industry and consultants. Financial risks, regulatory changes and community preferences are mentioned less often by regulators compared to mining industry and consultants.

TABLE 4.8 Risks taken into account when developing / advising on completion criteria
Number of times mentioned are provided with percentage of total per stakeholder group in parentheses

What information source(s) do you use to guide the development of completion criteria? (tick as many as apply)	Industry # responses (%)	Consultants # responses (%)	Consulting # responses (%)	Total times mentioned
Financial risks (e.g. company resources)	24 (7.2%)	11 (7.5%)	12 (8.3%)	47
Erosion risks	24 (7.2%)	11 (7.5%)	11 (7.6%)	46
Failure of vegetation establishment	25 (7.5%)	9 (6.1%)	12 (8.3%)	46
Impacts on groundwater	24 (7.2%)	10 (6.8%)	11 (7.6%)	45
Impacts on surface water	26 (7.8%)	9 (6.1%)	6 (4.1%)	41
Regulatory changes	20 (6.0%)	9 (6.1%)	11 (7.6%)	40
Acid drainage	20 (6.0%)	9 (6.1%)	10 (6.9%)	39
Landforms not created to design standards	19 (5.7%)	10 (6.8%)	10 (6.9%)	39
Human access to relinquished mine site	18 (5.4%)	9 (6.1%)	11 (7.6%)	38
Extreme weather events	18 (5.4%)	11 (7.5%)	9 (6.2%)	38
Ecological communities do not develop	19 (5.7%)	10 (6.8%)	8 (5.5%)	37
Impacts on threatened flora and fauna	22 (6.6%)	8 (5.4%)	5 (3.4%)	35
Climate change effects (long term)	16 (4.8%)	6 (4.1%)	9 (6.2%)	31
Litigation over environmental or social outcomes	12 (3.6%)	4 (2.7%)	8 (5.5%)	24
Community expectations being too high	15 (4.5%)	5 (3.4%)	4 (2.8%)	24
Cumulative risks across the catchment	12 (3.6%)	8 (5.4%)	3 (2.1%)	23
Community changing their preferences	16 (4.8%)	5 (3.4%)	2 (1.4%)	23
Other	5 (1.5%)	3 (2.0%)	3 (2.1%)	11

4.3.7 Monitoring

Progress towards meeting completion criteria are typically evaluated by comparing outcomes against benchmarked analogue/reference sites, or by monitoring whether a system is moving towards a stable system (Appendix 4.5.2). The main considerations for mining industry and consultants when choosing a reference site are:

- Matching anticipated end land use
- Suitability to end land use
- Matching pre-existing vegetation at the mine site
- Proximity to the mine site
- Selection is based on what's achievable

Monitoring methods used by industry and consultants to assess progress towards completion criteria are listed below. These monitoring methods are (a) chosen to address specific completion criteria; (b) based on previous company experiences; and (c) chosen to detect early effectiveness of interventions (Appendix 4.5).

- Vegetation transects
- Ecosystem/Landscape Function Analysis
- Remote sensing
- Soil and/or water testing
- Erosion/landform stability plots

Other evaluation methods mentioned are permanent vegetation plots, fauna trapping, agricultural trials, visual inspections, or combinations of the above.

Frequency of monitoring is highly site-dependent, but typically occurs annually during the early stages of rehabilitation and then periodically at increasing intervals (e.g. 1, 2, 3, 5, 10, 20 years from rehabilitation completion).

Regulators were also asked what key items they would like to see in a monitoring program, and what is 'typical' in closure plans assessed (Table 4.9). Like industry and consultant responses, regulators want to see comparisons against benchmarked analogue/reference sites. Some items that regulators want to see in closure plans, but that are not always included, are details about the specific data to be collected, and details about the monitoring techniques to be used.

TABLE 4.9 Regulators' responses on monitoring programs
Number of times mentioned are provided with percentage of total provided in parentheses

	What key items do you want to see in a monitoring program? (Pick up to 4)	Which of these is/are typically included in monitoring programs?
Benchmarked against analogue/reference sites	9 (21%)	6 (17%)
The plan details what specific data will be collected	6 (14%)	3 (9%)
Monitoring plans are supported by risk assessments	5 (12%)	6 (17%)
Monitoring techniques are specified in the plans	5 (12%)	1 (3%)
The plan details a time schedule for data collection	5 (12%)	8 (23%)
The plan details how reference sites were chosen	4 (9%)	3 (9%)
Benchmarked against ISO or other standards	3 (7%)	–
Monitoring plans are developed in collaboration with independent scientists	3 (7%)	–
Monitoring is performed by independent consultants	1 (2%)	1 (3%)
Monitoring is performed at regular time intervals	–	5 (14%)
Other	2 (5%)	2 (6%)
Total number of answers provided	**43**	**35**

4.3.8 Engagement

All respondents were asked what key (other) regulator(s) (Table 4.10) and stakeholders (Table 4.11) were engaged/consulted with when developing/advising on mine closure plans. Although the EPA is part of DWER, the Pastoral Lands Board is part of DPLH, the Conservation and Parks Commission is part of DBCA, and the Pilbara Development Commission is part of DPIRD, these entities were presented separately to assess whether respondents engage differently with specific agencies. Nevertheless, from written comments to the survey, four respondents chose to answer for the overall relevant department rather than specific commissions/agencies.

Consistent across all stakeholders, the main regulators involved in the development of mine closure plans are the Department of Mines, Industry Regulation and Safety (DMIRS); the Department of Water and Environmental Regulation (DWER) and its incorporated Environmental Protection Agency (EPA); and the Department of Biodiversity, Conservation and Attractions (DBCA).

The Department of Jobs, Tourism, Science and Innovation (DJTSI) is involved only where State Agreement Act sites are concerned. Interesting is the relatively low engagement with the Pastoral Lands Board and the Department of Planning, Lands and Heritage (DPLH) given that (a) this Department is the ultimate custodian of all pastoral and Unallocated Crown Lands, and (b) 35 of the mining industry respondents identified pastoral as their anticipated post-mining land use. Also noteworthy is that mining industry respondents were the only ones to indicate that they engage directly with local governments. Surprisingly, there are four respondents who stated that they do not engage with any regulators (Table 4.10).

Mining industry and consultants were asked whether they have one or multiple points of contact with the regulator. The vast majority (72% of mining industry and 100% of consultants) stated that they liaise with different people. This means that advice provided by a regulator could vary depending on the contact person involved.

Finally, respondents commented on the community stakeholders involved when developing completion criteria. The majority of respondents communicate with traditional owners and neighbouring (agricultural) landholders, whilst a small portion of mining industry proponents (11%) and consultants (35%) stated that they do not engage with community stakeholders. A few mining respondents also mentioned shire councils and natural resource management (NRM) groups as relevant community stakeholders.

TABLE 4.10 Key regulator(s) engaged with when developing completion criteria / assessing mine closure plans

Number of times mentioned are provided with percentage of total per stakeholder group in parentheses

Key regulator(s) engaged (select as many as apply)	Mining industry	Consulting business	Regulators
DMIRS (Dept. Mines, Industry Regulation and Safety)	29 (23%)	16 (24%)	9 (19%)
DWER (Dept. Water and Environmental Regulation)	22 (18%)	9 (13%)	9 (19%)
↳ EPA (Environmental Protection Agency)	15 (12%)	9 (13%)	7 (15%)
DBCA (Dept. Biodiversity, Conservation, Attractions)	15 (12%)	9 (13%)	3 (6%)
↳ Conservation and Parks Commission	3 (2%)	1 (1%)	4 (9%)
DJTSI (Dept. Jobs, Tourism, Science, Innovation)	6 (5%)	5 (7%)	5 (11%)
DPLH (Dept. Planning, Lands, Heritage)	9 (7%)	2 (3%)	3 (6%)
↳ Pastoral Lands Board	1 (1%)	4 (6%)	2 (4%)
DPIRD (Dept. Primary Industries and Regional Development)	3 (2%)	2 (3%)	2 (4%)
↳ Pilbara Development Commission	–	1 (1%)	–
Local government	9 (7%)	1 (1%)	–
Forest Product Commission	4 (3%)	1 (1%)	1 (2%)
We don’t engage with regulators	3 (2%)	1 (1%)	–
Water Corporation	1 (1%)	1 (1%)	–
DLGSCI (Dept. Local Government, Sport and Cultural Industries)	–	1 (1%)	–
Other	4 (3%)	4 (6%)	2 (4%)

TABLE 4.11 Key community stakeholder (s) engaged with when developing completion criteria / assessing mine closure plans

Key community stakeholders engaged	Times mentioned
Traditional owners/Native title group	22
Pastoralists/Agricultural landholders	20
Shire council/Local Government	15
Local community groups/NGOs	7
Catchment NRM groups	4
Other mining companies	3
Wildflower Society	2
Local businesses	2
Universities	2
Kings Park & Botanic Gardens	1

4.3.9 Resources

In the last two questions of the survey, respondents were asked about the resources (financial, knowledge, staff, practical skills etc.) needed to meet (industry), develop (consultants), or advise on (regulators) completion criteria (Table 4.12). The majority of the industry respondents stated that they have sufficient resources available, with a lack in staff being the primary constraint. Consultants typically mention a lack in biophysical or ecological data as a constraint. Most regulators stated that they lack adequate resources but did not provide further explanation.

Contrary to expectations, smaller mining companies (operating revenue less than $100 million/yr) were significantly more likely to report having sufficient resources, compared to mid-size and large companies ($p<0.1$). This contrasts with a widespread perception among closure professionals that small companies often lack the resources and knowledge to develop completion criteria to the level of detail and rigour required by the regulator. Thus, a question to be further explored would be whether small companies perceive having sufficient resources because, a) they are unaware of their unmet regulatory requirements, or b) because their mine closure plans are approved, despite their shortcomings.

TABLE 4.12 Respondents' assessment of resource availability to meet/develop/advise on mine completion criteria or mine closure plans
Number of times mentioned provided

Does your organization have sufficient resources to meet/ develop/advise on mine completion criteria or mine closure plans?	Mining industry	Consulting business	Regulators
Yes we have sufficient resources	27	7	2
We lack staff	4	–	2
We lack knowledge/data	2	6	1
We lack financial resources	2	–	–
We lack practical skills	1	–	–
We lack guidance from regulator	–	2	–
We lack examples of successful mine closures	–	1	1
We don't have enough time available	–	–	2
We don't have sufficient resources available (no explanation)	2	1	6
Total number of answers provided	**38**	**17**	**14**

Industry members and consultants were also asked whether the current resources provided by the regulator(s) are sufficient to help the planning of completion criteria. About a third of respondents agreed that there is sufficient guidance available (Table 4.13). However, at least one-fifth of respondents stated that government departments lack consistent, knowledgeable staff to evaluate mine closure plans. One respondent commented that: *"Different people at [the Department] means revisiting the same conversations over and over again"*. There was also a call for guidelines and examples for developing completion criteria, and increased consistency in expectations across Government departments.

TABLE 4.13 Respondents' assessment of resource provided by the regulator(s) to help planning of completion criteria

Are the current resources provided by the regulator(s) sufficient to help your planning of completion criteria? (# of times mentioned)	Mining industry	Consulting
Yes, there is sufficient guidance available	13	6
We need access to consistent staff with the appropriate knowledge	7	4
We need guidelines for developing completion criteria	5	1
We need greater alignment between government departments	3	2
We need more realistic criteria expectations	2	2
We need faster response times to submissions	4	0
We need more policy guidance on mine relinquishment	3	0
We need defined examples of expectation and benchmarks	2	0
We need more sharing of rehab data	1	1
Total number of times mentioned	**40**	**16**

4.4 Conclusion

This is the first time that an industry-wide investigation has been conducted to capture and analyse multiple stakeholders' perspectives around the development of mine closure completion criteria. We conducted semi-structured, qualitative interviews with 26 participants and a survey of 75 respondents, both of which included mining industry proponents, consultants involved with developing mine closure plans or completion criteria, and government regulators who assess or provide input into mine closure plans and completion criteria.

While the sample was small given the volume of number of stakeholders involved in mine closure, interesting trends could be observed in the data. Results were comparable between the interviews and the survey. Industry proponents and consultants had very similar opinions. They often commented on the regulator as lacking capacity, knowledge and a consistent coordinated approach to mine closure. Indeed, response from most regulators also indicated that they lack sufficient resources to adequately develop guidance for mine completion criteria development. This report and framework presented is a response to the need for such guidance.

4.4.1 Messages for industry proponents and consultants

The primary mine closure roadblock is a lack in knowledge. Many respondents welcomed the development of a framework for developing mine completion criteria. This would provide clarity about the level of detail required in closure criteria, and examples of what is acceptable to regulators. Areas for industry to improve include:

1. Sufficient investment in financial and staff resources for rehabilitation and closure, not only towards the end of a mine's life-time, but right from the start (government respondents commented that *"There is insufficient internal (mining company) closure capability / resources as environmental management / compliance is seen as a cost rather than a key factor of social licence to operate"*; and that *"Miners see completion criteria and rehab as something to consider at the end or towards the end of a mine's life and thus don't consider it to be an integral part of the mine's life and the mining development plan"*).
2. Invest in improving science-based knowledge of what are achievable rehabilitation standards in WA. Collecting and sharing baseline monitoring data across industry will be important to understand the core components of successful rehabilitation (*"In WA we simply don't have the knowledge of what is actually possible and how long it will take"* (consultant); *"Lack of advanced rehabilitation in the region from which learnings can be taken to feed more achievable completion criteria"* (mining proponent)).

During interviews, concerns were expressed that smaller companies may (a) have limited resources (financial and staff) available, resulting in less capacity for research, and (b) lack an internal knowledge base to set realistic, measurable, completion criteria compared to the larger miners. However, the results of this survey do not provide evidence for this. In fact, smaller companies were more likely to agree that they have sufficient information and resources available to meet current completion criteria. They were also more likely to agree that the regulator imposes additional standards on previously approved criteria, which may be indicating that smaller miners engage less regularly with the regulator to negotiate on completion criteria.

Another concern (raised primarily by regulators and independent consultants) is a risk posed by divestment, as industry proponents plan to sell off their assets as a site nears its closure date. In such cases, proponents may sell off their liability by on-selling sites to (smaller) companies *"without the internal culture and commitment to achieve a good environmental outcome"*. There are opportunities for companies to build assurances around this issue, to increase regulators' trust and social licence to operate.

4.4.2 Messages for regulators

There were several recurring comments from proponents and consultants about challenges related to government policies and Departments' capacity to guide closure criteria. Indeed, most regulators agreed that they lack the adequate resources (knowledgeable staff and time) to guide the development of mine closure plans. Reflective of the background of the majority of respondents, there were more critical recommendations for regulators than for industry. Study results pointed at the need to:

1. Develop a consistent, coordinated approach to completion criteria across government departments, and ensure that the regulator who signs off on the ultimate liability for mines being relinquished to government is involved in the process (*"The mining proponent rarely negotiates with the ultimate custodial authority – DMIRS are not the custodial authority, they are only administering tenement conditions – the mining proponent needs to deal / negotiate with the custodial authority to achieve the needs of the ultimate land manager / owner"*).
2. Provide clear guidelines and examples ('direction') on what are acceptable completion criteria (*"The most important is a lack of understanding of an appropriate approach to working out what are the SMART criteria for all the relevant aspects for their site. I'm hoping that having a framework to help guide companies on the process and provide some examples of what works and what doesn't will help many companies improve their development of completion criteria"*).
3. Consider alternative PMLUs other than the pre-mining land use (where possible given legal constraints). One respondent stated that there is a *"Lack of ability for the regulator to think outside the box as to what the best end use for that particular parcel of land is post operations"*.
4. Set realistic standards that are achievable based on the current state of knowledge and suited to the life-stage of the mine (*"It is difficult if not impossible to match pre-existing ecosystem"; "A better awareness in DMIRS of achievable, cost-effective criteria"*).

Despite the challenges identified, there were also positive comments that demonstrated opportunities. There is already a lot of knowledge available at different companies, expert consultancies and within government agencies. There is a need to share this knowledge to bring together the available information around rehabilitation techniques, closure objectives and measurable completion criteria. The current project aims to do exactly this by developing a structural framework, based in science, industry feedback and case studies, to guide the development of completion criteria (Chapter 2).

Photo courtesy: Renee Young

4.5 Appendices

4.5.1 Sample characteristics

What was your company's approximate operating revenue in the 2016-17 financial year?	Mining industry	
	# resp.	%
< 1 million	3	7.5
1 – 9 million	3	7.5
10 – 49 million	3	7.5
50 – 99 million	2	5.0
100 – 499 million	4	10.0
500 – 999 million	1	2.5
1 – 5 billion	4	10.0
> 5 billion	9	22.5
Don't know	11	27.5
TOTAL	**40**	**100**

What is the approximate size of your company?	Consulting	
	# resp.	%
Large consulting business with offices in multiple (intern)national locations	5	27.8
Large consulting business with several offices in Western Australia	0	0.0
Small-medium consulting business with one office in Perth (or elsewhere in WA)	8	44.4
Sole trader	4	22.2
Other, namely	1	5.6
TOTAL	**18**	**100**

4.5.2 Monitoring

How do you typically evaluate progress towards completion criteria? (Tick as many as apply)	Mining industry		Consulting	
	# answers	%	# answers	%
Compare against benchmarked analogue/reference sites	25	42	15	40
Monitoring whether the system's trajectory is towards a stable system	24	41	15	40
ISO or other standards	5	8.5	2	5.3
No stated benchmark	3	5.1	0	0.0
Compare against agreed criteria/outcomes	1	1.7	3	7.9
Other	1	1.7	3	7.9
TOTAL	**59**	**100**	**38**	**100**

What evaluation/monitoring method(s) do you typically use to assess completion criteria?	Mining industry		Consulting	
	# answers	%	# answers	%
Vegetation transects	23	18	14	20
Ecosystem Function Analysis/ Landscape Function Analysis	19	15	11	16
Remote sensing	15	12	12	17
Soil and/or water testing	23	18	7	10
Erosion/landform stability plots	18	14	9	13
Permanent vegetation plots	15	12	7	10
Fauna trapping	9	7	2	3
Grazing / cropping trials	1	1	2	3
Other (visual monitoring, combination of methods, …)	5	4	5	7
TOTAL	**127**	**100**	**69**	**100**

What are the main reasons for choosing that/those monitoring method(s)? (Pick up to three)	Mining industry		Consulting business	
	# answers	%	# answers	%
To address our specific completion criteria	26	30	12	29
Based on our previous experiences	18	21	10	24
To detect early effectiveness of interventions	15	17	8	19
To improve statistical efficiency	8	9	4	10
Based on referenced best practice	6	7	4	10
Based on external guidelines	8	9	0	0
Based on examples from other businesses	3	4	1	2
Other (e.g. based on approval processes)	1	1	3	7
Don't know	1	1	0	0
TOTAL	**86**	**100**	**42**	**100**

4

CHAPTER

Photo courtesy: Renee Young

5
CHAPTER

5 Case Studies

5.1 Introduction

Mine closure plans are publicly available but do not include the level of detail required to understand the context for, and history of, the development of completion criteria for mine rehabilitation. The purpose of this section is to present three case studies of mining operations in Western Australia. Specifically, the approach to, and experiences of, three mining companies in the development of completion criteria and monitoring outcomes appropriate to specific post-mining land uses is documented. This section provides some insights to industry, particularly to companies yet to embark on mine closure, by identifying examples of key challenges and opportunities for rehabilitation success. It also provides a record of what has been achieved to date within the current regulatory framework and availability of research to guide leading practice. Ultimately, by sharing lessons learned with industry, regulators, environmental consultants, researchers and other stakeholders, this report aims to increase efficiencies for best practice mine rehabilitation moving forward.

5.2 Selection of case studies

Case studies included in this section were selected through a stakeholder consultation process. Five key themes were identified, which would be used to select the case studies (Table 5.1). The first theme is bioregion, which defines mining activity according to underlying geology, and biophysical constraints to mine rehabilitation especially climate and diversity of native vegetation. There are at least 27 bioregions in Western Australia based on climate, geology, landform, native vegetation and species information (Thackway and Cresswell 1995). This Interim Biogeographic Regionalisation for Australia (IBRA) classification is more detailed than John Beard's original vegetation maps of the state, which include just seven regions: Kimberley, Great Sandy Desert, Great Victorian Desert, Nullarbor, Pilbara, Murchison and Swan (Beard 1990). Neither the IBRA nor Beard bioregions correspond to the nine socio-economic regions recognised by the Government of Western Australia (*Regional Development Commissions Act 1993*). Mining activity dominates the economy of six of the nine socio-economic regions: Kimberley (Diamonds, zinc, lead, nickel), Pilbara (iron ore, manganese), Gascoyne (salt, gypsum), Mid-west (iron ore, gold, nickel), Goldfields-Esperance (gold, nickel, platinum) and Peel regions (bauxite, mineral sands).

Photo courtesy: Mike Young

TABLE 5.1 Themes capturing key challenges for mine rehabilitation and closure in Western Australia

Theme	Theme categories
1. Biogeographic region	Between 7 and 27 bioregions depending on classification system
2. Socio-economic region	• Pilbara • Goldfields-Esperance • Peel or Mid-west • Other e.g. Kimberley
3. Company size	• Small • Divestment • Large
4. Type of mine	• Surface mining (e.g. mineral sands, bauxite) • Open cut (e.g. gold, iron ore)
5. Mine life stage	• Early stage (< 10 years) • Mature (>10 years) and sole operator • Mature (>10 years) and multiple consecutive operators

Besides geographic location, case studies were selected according to the characteristics of the company and mine (Themes 3 to 5 in Table 5.1), which typically impact their capacity and challenges in the development of completion criteria and rehabilitation. Unfortunately, despite approaching several companies in the Goldfields, the project research team was unable to recruit a case study. One company did not respond to the invitation and three declined, indicating lack of sufficient experience to serve as case studies on rehabilitation and closure planning.

The Pilbara Region was prioritised given the significant impact of iron ore mining on the state's economy and the capacity for industry in the region to set a state-wide standard for best practice rehabilitation. Thus, the Pilbara case study consisted of the BHP Billiton Goldsworthy Northern Area mining project.

The second case study, Mount Gibson's Tallering Peak in the mid-west, was selected as an example of a mid-size company with successful definition and achievement of completion criteria. Lastly, Alcoa was included given its vast, internationally recognised experience in mine site rehabilitation in the Northern Jarrah Forest. Alcoa is one of the few companies to have achieved mine closure and relinquishment in Australia.

For each case study, a template of information was completed pertaining to the development of completion criteria and the company's experience of mine closure. Details were extracted from the published and grey literature in the first instance. In a second phase, knowledge gaps were filled by conducting personal interviews with industry personnel.

Photo courtesy: Mike Young

5.3 Summary of case studies

The case study component reports how three mining companies have approached the development of their completion criteria and associated monitoring program. Each case study includes the context for mine rehabilitation and finishes with future opportunities (Table 5.2). This section contains case studies for:

- BHP — Goldsworthy Northern Areas
- Mount Gibson Iron — Tallering Peak
- Alcoa — Northern Jarrah Forest.

TABLE 5.2 Case study summary

Company	BHP Western Australia Iron Ore	Mount Gibson Iron	Alcoa of Australia
Size of company (per stock exchange)	AUD 3.21 billion	AUD 0.6 billion	AUS 16.15 billion (Global company worth)
Case study	Goldsworthy Northern Areas	Tallering Peak	Northern Jarrah Forest
Mineral resource	Iron ore	Iron ore	Bauxite
Mining activity	Open cut	Open cut	Surface
Economic region	Pilbara	Mid-west	Peel
Climate	Semi-arid	Semi-arid	Mediterranean
Soils	Shallow soils over banded ironstone formations	Shallow soils over banded ironstone formations	Lateritic (gravelly)
Native vegetation	Hummock grassland	Shrubland	Jarrah forest
Pre-mining land use	Livestock grazing	Livestock grazing	Selective logging, recreational, water catchment
Closest town or city	Port Hedland	Geraldton	Perth
Key stakeholders	Pastoralists, local Aboriginal communities	Pastoralists	City dwellers
History of mining in region	1960s (iron ore); 1890s (gold)	Iron ore discovered in Tallering Range in 1871	1960s (bauxite)
Inherited land use legacies	Grazing impacts	Grazing impacts	Large, old trees with nest hollows reduced by logging
Post-mining land use	Probably livestock grazing but yet to be confirmed	Livestock grazing	Conservation, recreational, water catchment
What needs to be rehabilitated?	Waste rock dumps, pit lakes, mesa landforms, vegetation, fauna, ecosystem functions	Waste rock dumps, pit lakes, vegetation, ecosystem functions	Landform, vegetation, fauna, ecosystem functions
Rehabilitation challenges	Altered hydrology, acid pit lakes, landform stability, spatial scale, limited topsoil, intermittent rainfall, remoteness	Altered hydrology, landform stability, spatial scale, limited topsoil, intermittent rainfall, acid pit lake, feral grazers	Altered hydrology, recalcitrant species, phytophthora
Achieved mine closure?	Pending	Pending	Yes
Achieved relinquishment?	Pending	Pending	Yes, to DBCA
Legislative framework	State agreement	*Mining Act 1978*	State agreement

5.4 Results

The selected case studies have been instrumental in informing the framework for definition of completion criteria. While each case study provides a unique set of lessons learnt (see sections below), several common themes emerged.

First, the definition of completion criteria needs to be based on a clear outcome, which will then dictate the rest of the process. In the case of BHP, this is referred to as 'outcome-based' hierarchy for closure and rehabilitation (Source: BHP Billiton (2017) Figure 5.4). The hierarchy or step-wise process, as it is defined in the framework, should be in line with the overarching guiding principles of ensuing the site is safe, stable, non-polluting and able to self-sustain the agreed post-mining land use (DMP & EPA 2015).

Second, the references against which completion criteria are defined should not necessarily be limited to baseline conditions or analogues sites, which are the two most commonly used references at present time in Western Australia. Instead, targets where appropriate should be informed by a suite of conditions, drawn from various sources which may include field and laboratory trials. For example, BHP set completion criteria based on a rehabilitation trial that demonstrated the ability to regenerate following burning, in terms of key parameters such as vegetation cover, richness and density (Table 5.4). Similarly, Mount Gibson conducted Landscape Function Analysis (LFA) and vegetation monitoring on a rehabilitation trial in the waste landforms. The purpose was to analyse soil chemistry, test rehabilitation techniques for supporting vegetation growth and determine optimal seed mix for rehabilitation (see Section 5.6.2). As part of its extensive research program, Alcoa used evidence from permanent monitoring plots and research trials to show that understorey cover density and richness are within the respective ranges observed in forest reference sites (see Section 5.6.3).

Besides the company's own knowledge base, it is important to consider the guidance from a broad range of sources for the definition of completion criteria. While the industry survey (Table 4.5) shows that most proponents only refer to one or two key guiding documents, a large number of guiding documents and polices exist that can be useful in the definition of completion criteria. A concise, yet informative list of such documents is presented in the Mount Gibson case study (see Section 5.6.2).

Interestingly, industry-driven research and regulatory requirements can be progressed in a mutually beneficial manner, whereby rehabilitation success is driven by innovation, rather than regulation. Each of the companies featured in our case studies show the positive outcomes of prioritising innovation and achievements beyond the minimum standard. For decades, Alcoa has heavily invested in its own cutting-edge research program to understand the opportunities and limitations in terms of rehabilitation of the mines in the Northern Jarrah Forest. The lessons learnt from such research have thus been key to inform rehabilitation standards in Western Australia, and internationally. While for most mining operators it is common practice to adhere to their minimum legal requirements, Alcoa has shown that aiming at the highest standards has allowed them to remain compliant in the long term, even as regulation become stricter overtime. In the Pilbara, BHP's investment in research has substantially improved rehabilitation outcomes for the Pilbara region.

A key benefit of rehabilitation research is its use in the development of leading indicators i.e. those that can be measured at early stages of rehabilitation and that provide an accurate estimation of future rehabilitation success. As noted by BHP (Section 5.6.1), closure outcomes are controlled by planning, design and execution activities and, thus, leading indicators should focus on provision of a suitable growth medium and local plant species. Some practical examples of leading indicators can be found in Mount Gibson's use of LFA (Section 5.6.2) or Alcoa's use of legume count as a proxy for soil nitrogen (Section 5.6.3).

The success of rehabilitation of mine sites is assessed on several indicators, although it is typically understood that some may be more critical than others. To make such distinction, BHP employs a risk-assessment process that ranks knowledge gaps based on their potential to negatively impact closure outcomes (see Section 5.6.1). Consequentially, high-priority knowledge gaps are associated with the necessary research programs in order to define detailed completion criteria that will ultimately support relinquishment.

Through the mine closure planning process, rehabilitation outcomes should be regarded as dynamic, and thus revised in successive version of mine closure plans as appropriate. The three case studies exemplify how closure objectives and completion criteria are revised in an iterative manner. As mining operations progress and change occurs, for example as a result of stakeholders' concerns or environmental factors, it is necessary that closure planning and rehabilitation practices adapt to such changes. For example, BHP employs an adaptive management approach (Source: BHP (2018) Figure 5.5), whereby knowledge gaps are repeatedly addressed as potential risks or impacts are better understood. Similarly, Alcoa carries out early assessments of rehabilitation status against the set completion criteria, which then trigger the undertaking of corrective actions, where needed (see Section 5.6.3).

In order to inform the need for corrective action, data monitoring should be carried out at regular intervals and be targeted at those indicators that serve to define rehabilitation success. Alcoa's accurate monitoring scheduling (e.g. at nine and 15 months — see Section 5.6.3) allows the tracking of progress along the desirable rehabilitation trajectory. In this way, the risk of non-fulfilment of completion criteria is minimised, as outcomes diverging significantly from the set targets can be addressed at early stages of rehabilitation. Advances in monitoring technology, as used by all three featured companies, are already providing dramatic improvements in the way data is collected and used for assessing rehabilitation success.

Finally, the three case studies feature in this report illustrate the need to assess rehabilitation success in a holistic manner, and not only as a compilation of independent criteria. For instance, BHP develops criteria across mine areas and domains in a way that failure to achieve a certain criterion in certain areas does not automatically mean that the land is unsuitable for its intended purpose (Section 5.6.1). Such a holistic approach becomes critical in situations such as that experienced by Mount Gibson's Tallering Peak. Although the mine was close to meeting all completion criteria in 2016, a dry spell throughout 2017 resulted in one vegetation criterion falling slighting below its agreed level in one particular area of the site.

5.5 Conclusions

The case studies highlight the different journeys companies undertake to rehabilitate their mining activities. Creating a framework to guide the development of completion criteria and risk-based monitoring programme for mine rehabilitation in Western Australia. Indeed, the experiences of the three mining companies reinforce the ample variation in rehabilitation contexts, including differences in minerals, extraction processes, landscape, climate and legislative requirements. Despite context dependencies evident in development of mine completion criteria, the three case studies provide some common lessons to guide future development of completion criteria for mine rehabilitation and closure. The methodology used could serve as a template for creation of additional case studies.

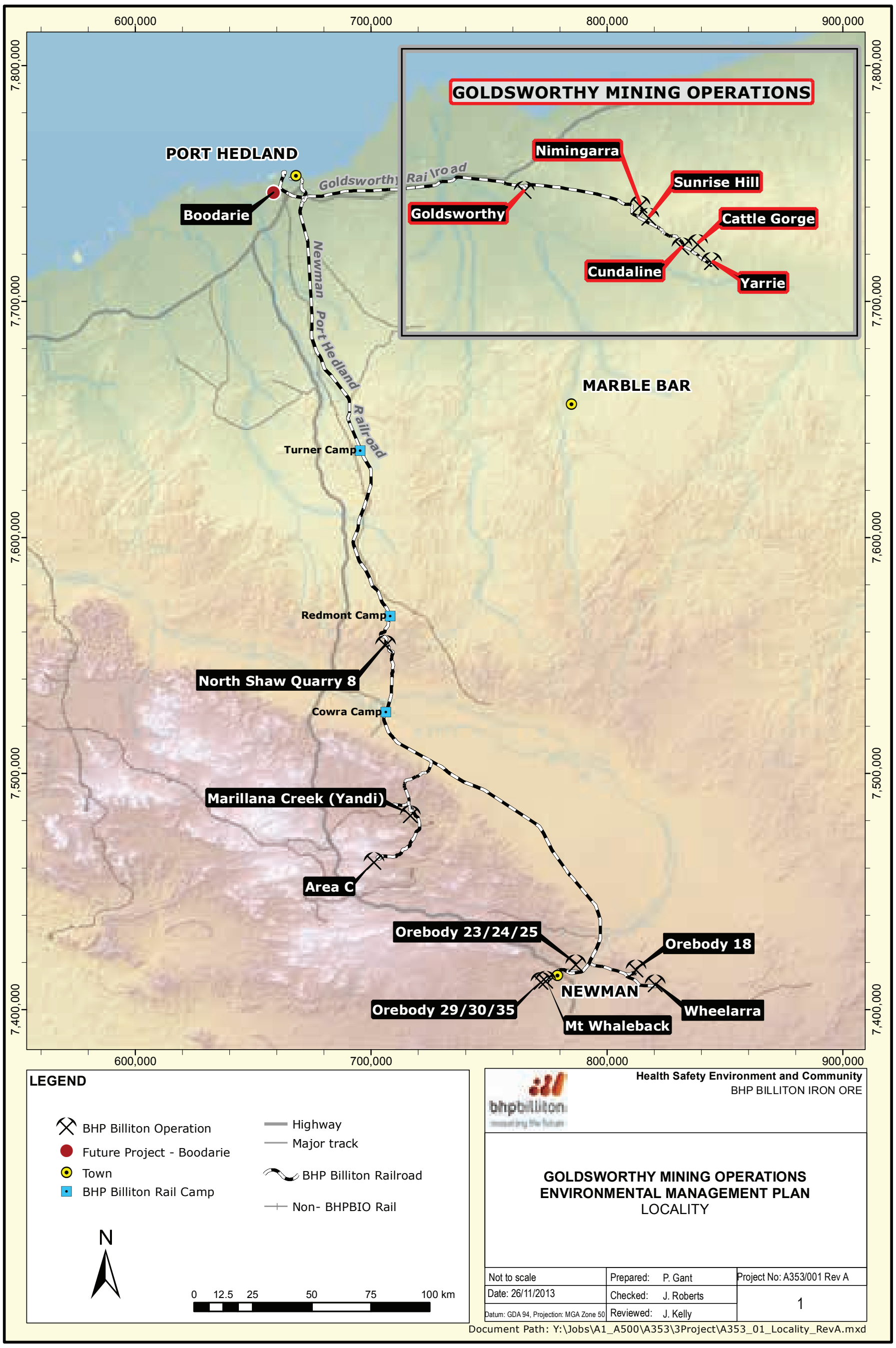
Photo courtesy: BHP

5.6 Appendices – Case studies

5.6.1 BHP – Goldsworthy Northern Areas (GNA)

Background

Goldsworthy Northern Areas (GNA) is located 178km east of Port Hedland (Source: BHP Billiton (2013) Figure 5.1). The GNA Hub consists of eight mines located in two areas; Yarrie (comprising Yarrie, Cattle Gorge, Cundaline and Callawa mines) and Nimingarra (comprising Nimingarra, Midnight Ridge, Shay Gap and Sunrise Hill mines). The Goldsworthy mine and associated former townsite are not part of the GNA Hub.



Source: BHP Billiton (2013)

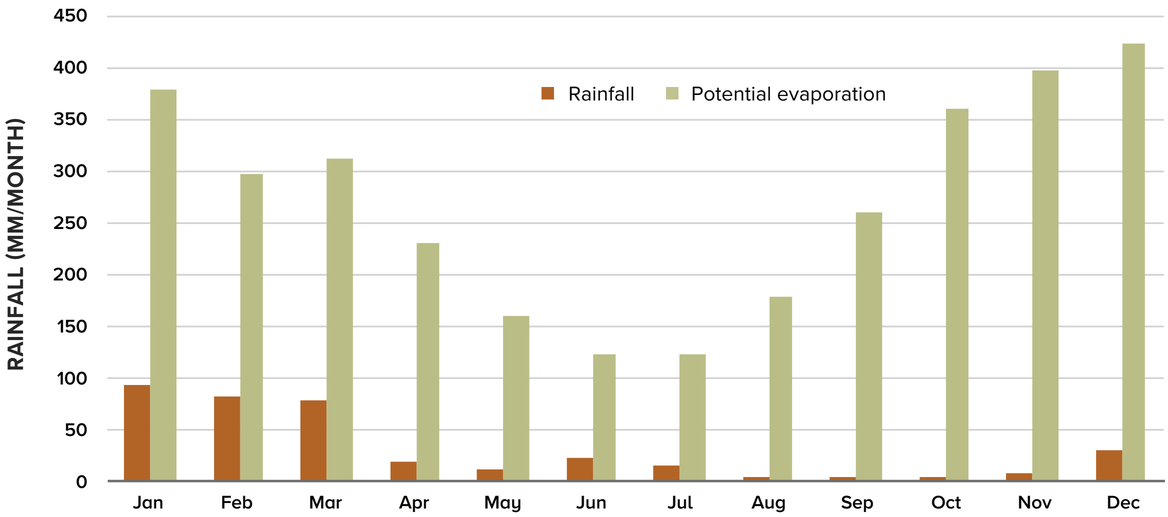
FIGURE 5.1 Location of Goldsworthy Northern Areas

ENVIRONMENTAL CONTEXT

The Goldsworthy-Nimingarra ores are predominantly high-grade microplaty hematite lode ores, distinct in character and origin from ore at other BHP mines in the region as they are developed within the approximately three-billion-year-old Archean granite-greenstone terrane. Deposits are distributed in a thick sequence of banded iron formation (BIF) in the Cleaverville Formation along the northern margin of the exposed Pilbara Craton (BHP 2011). The geomorphology consists of low rocky hills, plateaux and ridges with wide sandy plains containing ephemeral creeks (Dames & Moore 1992). Soils are skeletal, shallow, stony soils on the hills and ridges and sandier on the plains (Van Vreeswyk *et al.* 2004). As one of the oldest land surfaces on earth, it hosts exceptionally high biotic diversity and endemism (Pepper *et al.*, 2013), although much of the biodiversity and its conservation status still remain undescribed (EPA 2014).

The Pilbara has a semi-arid to arid climate with highly variable rainfall averaging 200mm to 350mm and an annual evaporation rate of over 4000mm (Johnson & Wright 2003). The Goldsworthy weather station recorded annual rainfall extremes of 72mm and 736mm, with an average of 329mm over 26 years of recording (BoM 2018). GNA experiences annual mean maximum temperatures of 28–40°C with extremes over 49°C (BoM 2018).

Rainfall events are infrequent, irregular and intense, with the majority of rain associated with tropical storms during summer (Source: DPIRD (2018) Figure 5.2). The boom and bust rainfall contributes to irregular seedling recruitment events and limits opportunities for vegetation establishment in mine rehabilitation, so the timing of rehabilitation events to coincide with expected rainfall is critical to their success (Lewandrowski et al. 2017a,b; Muñoz-Rojas *et al.* 2016b).



Source: DPIRD (2018)

FIGURE 5.2 Comparison of monthly rainfall to potential evapotranspiration for Marble Bar

Mining operations are situated at the north-east edge of the Fortescue botanical district which is a recognised biodiversity hot spot (Carwardine *et al.* 2015). Trees and shrubs are sparse except along watercourses and vegetation typically comprises 83% hummock grassland with 2% trees, 2% tall shrubs, 5% low shrubs and 8% tussock (Van Vreeswyk *et al.* 2004). In 1992, at the time of assessing the environmental impact of Yarrie mine, vegetation species were noted to be widespread across the area with no rare flora identified (Dames & Moore 1992).

Fauna surveys observed that birds, amphibians and reptiles present were common and widespread but the possible presence of conservation significant species were noted including the Pebble-mound Mouse (*Pseudomys chapmani*), Bilby (*Macrotis lagotis*), Mulgara (*Dasycerus cristicauda*), Lesser Stick-nest Rat (*Leporillus apicalis*), Grey Falcon (*Falco hypoleucos*), Pilbara Rock Python (*Moreila olivaceus barroni*), Peregrine Falcon (Falco peregrinus), Long-tailed Dunnart (Sminthopsis longicaudata), Woma Python (Aspidites ramsayi), Rothschild's Rock Wallaby (*Petrogale rothschildi*), Orange Horseshoe-bat (*Rhinonicteris aurantius*) and the Ghost Bat (*Macroderma gigas*) (Dames & Moore 1992). The relatively small land area affected by mining (270ha total disturbance at Nimingarra-Yarrie) (BHP Billiton 2013) may have protected native flora and fauna from the impacts of mining. However, the specific habitat requirements of some species make them especially vulnerable to mining impacts, such as bat roost destruction or disturbance (Armstrong 2010).

Photo courtesy: Lochman Transparencies

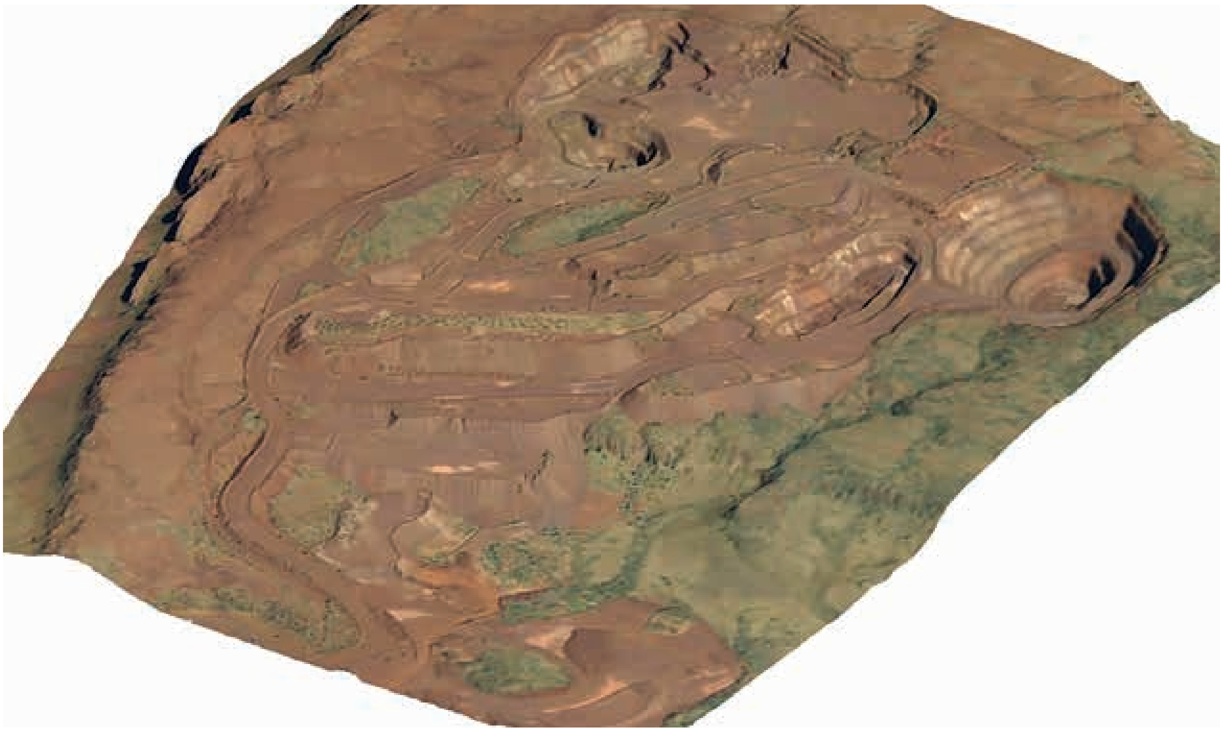
PREVIOUS LAND USE

The Goldsworthy region was originally home to the Njamal people, with the closely related Ngarla to the west. The Traditional Owners describe the area as good for hunting and ochre collection and state that spiritual obligations to country still exist despite mining activity (Brown (on behalf of the Ngarla People) v State of Western Australia 2010; Smith 2002). Njamal people continue to live in the area in the nearby towns of Marble Bar, Nullagine and Port Hedland and have been engaged in relation to mine closure planning (BHP Billiton 2013).

The mining leases (established 1964) are mostly located on the pastoral leases of Muccan Station (established 1879) and Yarrie Station (established 1888). These stations historically ran up to 20,000 sheep but now operate as cattle stations around the mines. The surrounding land comprises unallocated crown land and pastoral leases including the Pardoo, Warrawagine, Coongan and De Grey stations.

MINING OPERATIONS

Mining at Shay Gap and Sunrise Hill was approved in 1972 and at Nimingarra in 1986. BHP acquired full ownership of the mines from Mount Goldsworthy Mining in 1991 and developed the Yarrie, Cattle Gorge and Cundaline mines between 1992 and 2009. BHP commenced progressive rehabilitation in 1995. In 2014, mining operations were suspended and a stewardship program of ‘no regrets’ demolition and rehabilitation is currently underway. In 2016 Cattle Gorge was rehabilitated as part of this stewardship program and is the most recent example of rehabilitation at the GNA Operation (Figure 5.3).



BEFORE

AFTER

FIGURE 5.3 Cattle Gorge before (top image) and after (bottom image) rehabilitation

The mining method employed at GNA was conventional drill, blast and haul with overburden either backfilled or stored in overburden storage areas (OSAs) (BHP Billiton 2013).

TABLE 5.3 Key closure features

Features	Mining area	Characteristics (mine voids) and rehabilitation status (OSAs)
Mine voids	Nimingarra	Three pits above water table and seven below water table
	Midnight Ridge	Above water table
	Sunrise Hill	Thirteen pits above water table and four below water table
	Shay Gap	Three pits above water table and three below water table
	Cundaline	Three above water table pits
	Cattle Gorge	One pit backfilled to above the water table and two above water table pits
	Yarrie	Four backfilled pits, four partially backfilled, two below water table pits and remaining pits above water table
Overburden Storage Area (OSA)	Nimingarra	Several OSAs were rehabilitated in 1995. Some are yet to be rehabilitated.
	Midnight Ridge	Rehabilitated
	Sunrise Hill	Several OSAs were rehabilitated circa 1995. Some are yet to be rehabilitated.
	Shay Gap	Town site rehabilitated circa 1995
	Cundaline	Two OSAs not yet rehabilitated
	Cattle Gorge	OSAs rehabilitated 2016
	Yarrie	Rehabilitation campaigns in 1998, 2003, 2004, 2009, 2010-11. Some OSAs still to be rehabilitated.
Infrastructure	Includes process infrastructure (e.g. crusher, conveyors, stackers) and non-process infrastructure (e.g. workshops, fuel storage, offices, water and power supplies)	
Roads and access tracks		

Source: BHP (2018)

Methodology

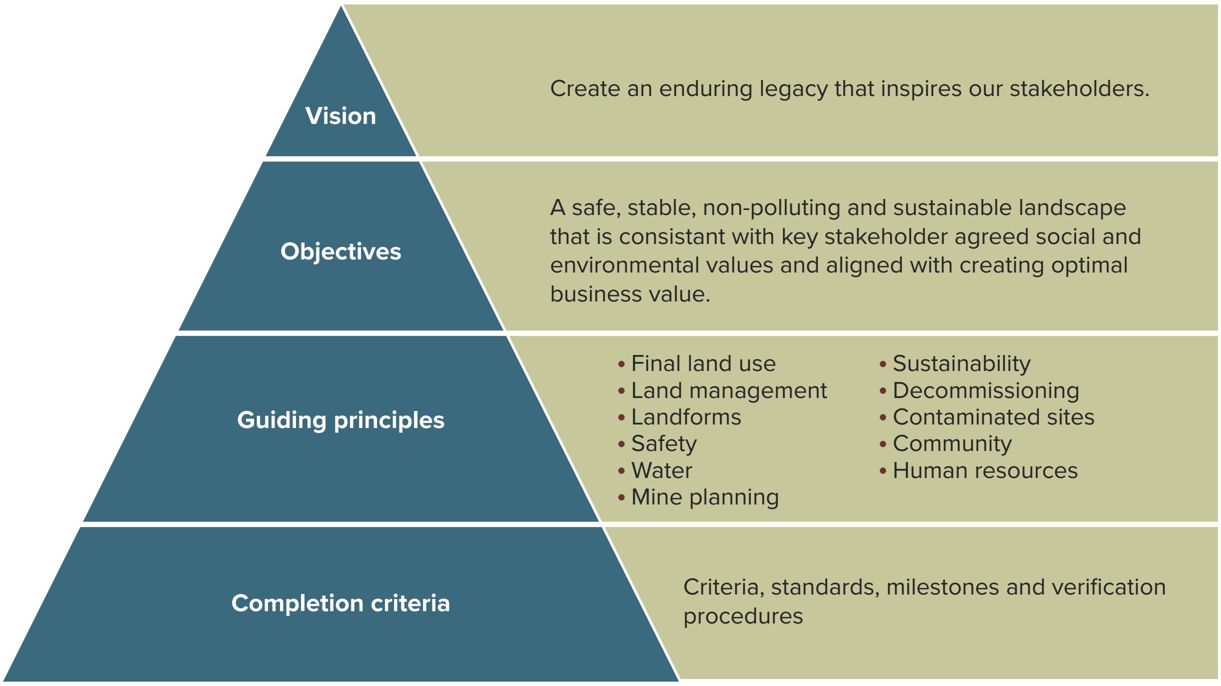
Research was split into three phases. Firstly, a site visit to Yarrie, Cattle Gorge, Nimingarra, Shay Gap and Goldsworthy was hosted by BHP staff on 7th–8th May 2018 to observe examples of rehabilitation completed over a 25 year period. Members of the WABSI Completion Criteria Project team travelled to site as guests of BHP.

Secondly, a document review was completed, primarily involving internal documents supplied by BHP and regulatory documents. Lastly a semi-structured interview was conducted via telephone with key personnel from the mining company. The aim of the interview was to fill knowledge gaps evident after the document review or to provide more detail on specific emergent themes. Results from the multiple information gathering methods were synthesised into a report addressing the research objectives outlined above.

Results

REHABILITATION OBJECTIVES

BHP's outcomes-based hierarchy for closure and rehabilitation is outlined in (Source: BHP Billiton (2017)) Figure 5.4.



Source: BHP Billiton (2017)

FIGURE 5.4 Outcomes Based Hierarchy

BHP's overarching objective for closure is to develop a safe, stable, non-polluting and sustainable landscape that is consistent with key stakeholder agreed social and environmental values and aligned with creating optimal business value (BHP Billiton 2013).

This objective is supported by a number of guiding principles (BHP 2018):

- **Informed planning and design:** rehabilitation and decommissioning requirements are considered at a mine deposit and regional scale, upfront and integrated into mine plans to achieve optimal business value and a sustainable final land use.
- **Sustainable final land use:** Final land use and rehabilitated areas meet stakeholder expectations and consider the following:
  - Local land management practices
  - Ongoing management requirements (e.g. roads and tracks)
  - Closure landform integration, including visual impacts, landform stability (physical and geochemical) and hydrological regimes
  - Local baseline conditions (e.g. flora, vegetation, fauna and fauna habitat)
  - Ecosystem resilience in terms of flora, vegetation, fauna, and surface and groundwater hydrology
  - Infrastructure transfer or decommissioning
  - Management or remediation of contaminated sites
  - Amenity

- **Safety:** All mine rehabilitation and decommissioning is planned so that the risks to health and safety of people within the BHP Western Australian Iron Ore's (WAIO) area of influence are minimised. Unauthorised public access risk will be managed through the implementation of controls in accordance with regulatory requirements and consideration of industry guidance.
- **Effective stakeholder engagement:** Transparent and proactive stakeholder engagement occurs for all planned activities that may impact surrounding communities, including consideration of communities impacted by closure.

Post-mining land use

Post-mining land use is the one of BHP's key guiding principles and plays a significant role in closure and rehabilitation planning. Important factors that are considered in the planning process to determine post-mining land use include:

- Meaningful stakeholder engagement
- Capacity of the land to support potential post-closure land uses
- Long-term environmental and demographic trends
- Regulatory and tenure requirements
- Proximity to communities, major infrastructure, water sources, conservation estates and areas of high biodiversity (BHP Billiton 2017).

The post-mining land use has yet to be confirmed with stakeholders but, given that GNA is located predominantly on pastoral tenements, the overarching post-mining land use for the area is proposed to be 'low-intensity grazing'. However, taking into account the capacity of the land to support these uses, BHP acknowledges that, at this stage, residual mine voids may not support a specific land use due to ingress and egress restrictions (BHP Billiton 2013). The productive use of areas disturbed by mining (including mine voids) is an area that is rapidly evolving and there are a number of examples of productive uses of mine voids in Australia and overseas (for example, pumped hydro-electricity scheme at Kidston mine in Queensland (GENEX 2017) and the landfill bioreactor at Woodlawn in New South Wales (Veolia 2017)).

GNA is located in an area that is being independently assessed for other regional development opportunities such as irrigated agriculture (DPIRD 2018) and solar power generation (Mella *et al.* 2017). These potential uses have not been specifically factored into GNA's completion criteria, but the current pastoral end land use will not prevent alternative future uses from being implemented.

Completion criteria development

GENERAL PRINCIPLES

Completion criteria are 'agreed standards of performance that indicate the success of rehabilitation and enable an operator to determine when its liability for an area ceases' (LPSDP 2016e). BHP's completion criteria cover the full scope of its guiding principles (see General Principles, above) and are progressively developed over the life of the mine with increasing detail and refined metrics over time (BHP Billiton 2017).

BHP recognises that closure outcomes are controlled by planning, design and execution activities. BHP's criteria, therefore, include both leading indicators describing the activities and designs necessary to achieve desired outcomes (e.g. landforms have been designed and constructed to take account of waste characteristics affecting stability), as well as lagging indicators which describe closure outcomes to be achieved (e.g. total native perennial vegetation cover to be ≥ 20%).

The land to which criteria are applied is altered fundamentally from its pre-existing condition. Criteria, therefore, need to be site specific and focus on what is required to make the land suitable for its end land uses rather than attempt to recreate a pre-mining environment. Not all criteria will apply to all areas of the site, particularly at a site like GNA that spans a wide area. The site may be split into sub-units to reflect different:

- Land capabilities
- Surrounding environmental conditions
- Stakeholder views and land use requirements.

One of the key challenges in developing and applying criteria is the inherently variable nature of the natural environment. Similar undisturbed areas often have different characteristics (spatially and temporally) and there have been instances where companies have developed numerical completion criteria that are not met by analogue sites. The Botanic Gardens and Parks Authority (BGPA) made the observation that the higher abundance of weed species in rehabilitation, relative to their abundance in analogues, could be a result of the unconscious selection of analogue sites that are unrepresentative of the broader rangeland landscape (BGPA 2017). The process of selection of analogue sites involves professional consultants reading the local landscape in the vicinity of planned rehabilitation and selecting undisturbed sites that are deemed to be appropriate analogues for a desired future state of the rehabilitation. This process would bias analogue sampling to be unrepresentative of the broad landscape and instead be representative of an ideal state. Analogues need to be used with care since the underlying structure of the mined landforms differs completely from natural landforms.

With this challenge in mind, BHP develops criteria which are intended to be viewed holistically across relevant domains and areas of the site such that failure to achieve certain criteria in some areas, does not automatically mean that the land is unsuitable for its intended purpose. The criteria are structured to:

- Clearly articulate the objective of each criterion — i.e. the intent of what should be achieved in closure.
- Describe the standard or milestone that is intended to be achieved. While a number of these standards may not be numerical, the qualitative descriptions define the expected actions or outcomes and are measurable through monitoring and audit. BHP's ongoing monitoring and research programs are designed to facilitate the development of numerical targets where these will add value to the assessment of closure outcomes.
- Define how BHP will demonstrate that a criterion has been met. The verification procedures outlined in BHP's criteria outline what is required to be measured to demonstrate achievement of each criterion.

Where specific criteria are not met, the objectives outlined for the criteria help to determine whether the standard of closure and rehabilitation may be acceptable when viewed holistically across the site.

Industry's understanding of closure and rehabilitation practice and achievable outcomes has improved over time and is still evolving. BHP's approach to developing criteria is, therefore, to start with criteria which are weighted towards leading indicators and qualitative descriptions of acceptable outcomes and to refine these with numerical targets as the results of trials and research become available.

One of the challenges of long-lived mining operations is that both the socio-economic context and natural environment surrounding the operation evolve over the life of the mine. This may necessitate a change in criteria to reflect different end land uses or changes to the natural environment. While BHP's approach maintains flexibility, there comes a point where certain approaches have been implemented and the range of outcomes that may be achieved by an area may be limited by the approaches applied. For example, at GNA a number of landforms were rehabilitated in the late 1990s to the leading practice standards of the day. The outcomes achieved by these landforms may be different to those achieved by more recently rehabilitated landforms. In recognition of this, early era completion criteria have been proposed for older areas of rehabilitation at GNA (Table 5.4).

TABLE 5.4 Goldsworthy Northern Areas completion criteria

Criterion	Criterion objective	Domain	Criterion standard or milestone	Proposed variation to criterion for early era rehabilitation	Verification procedure
1.1 Final Land Use	Agreed final land use has been determined in consultation with relevant stakeholders.	All	• End land use for the area is considered likely to revert to pastoral activity, or the inclusion in some form of natural conservation area. However, this would be determined in consultation with stakeholders, and approved by the administering authority during the life of the mine. • Specific rehabilitation objectives have been developed to ensure that, when met, areas will fulfil the post-mining land use requirements.	No variation proposed.	• Land use objectives are documented in the GNA MCP as reviewed and agreed by the key stakeholders.
2.1 Safety	There are no unsafe areas where members of the general public could gain inadvertent access.	All	• All hazards that could endanger the safety of any person or animal have been identified and eliminated, where practical. • All residual safety and health hazards have been identified and controlled in accordance with regulatory requirements and consideration of industry guidance.	No variation proposed.	• All relevant regulatory guidelines have been met unless otherwise agreed with the regulator. • All sites are assessed as acceptable with regards to safety by the District Mines Inspector.
2.2 Landform Safety	Final landforms are safe.	All	• Landforms are designed and constructed to address safety risks as described in criterion 2.1. They conform to DMIRS guidelines for structural stability, with no significant slumping or failure of accessible constructed slopes or berms. • No unacceptable hazards to humans or wildlife have developed thorough erosion, subsidence, Acid Mine Drainage (AMD) or otherwise.	No variation proposed.	• Report on landform construction methods (not applicable to early era landforms), and any additional maintenance works undertaken. • Rehabilitation inspections (including undertaken on maintenance earthworks) confirm earthworks have met final landform designs. • Rehabilitation monitoring results (including erosion monitoring). • Report on performance in relation to design criteria and DMIRS guidelines. • Inspections of the rehabilitated landforms have been conducted to monitor their stability over time, with monitoring conducted after each significant rainfall season.

Table 5.4 continues following page...

TABLE 5.4 Goldsworthy Northern Areas completion criteria

Criterion	Criterion objective	Domain	Criterion standard or milestone	Proposed variation to criterion for early era rehabilitation	Verification procedure
3.1 Visual Amenity	Visual amenity of constructed landforms is compatible with that of local Pilbara landforms.	All except mine voids	Within the constraints imposed by aspects such as the physical nature of the materials available, tenement boundaries, and proximity to water courses, landforms have been constructed to blend into the surrounding landscape. Landforms are consistent with the agreed final land use (criterion 1.1).	No variation proposed.	• Report on rehabilitation works confirms landform construction undertaken according to WAIO relevant procedure. • Rehabilitation inspections confirm earthworks have met final landform designs.
3.2 Waste Characterisation	Materials with poor physical or chemical properties do not compromise rehabilitation (landforms stability and revegetation).	Anywhere problem materials present	• An overburden storage plan for any new OSA is developed and incorporated into the life of mine plan prior to the commencement of ex-pit dumping activities. • All overburden placement in new OSAs has been undertaken in accordance with this plan. Mine waste material likely to provide a poor growth medium (e.g. dispersive and incompetent material), has been placed appropriately in the OSA.	• OSAs have already been constructed and there is limited information on 'as constructed' design. A suggested criterion is therefore: • The landform is stable and there are no areas where mine waste material placed at the surface is resulting in unacceptable outcomes to landform stability.	• Waste characterisation report available for review (not applicable to early era landforms). • Report on landform construction methods (not applicable to early era landforms). • Rehabilitation inspections confirm earthworks have met final landform designs.
3.3 Landform Stability	Constructed landforms are structurally stable.	All	Post-mining landforms have been designed and constructed with consideration of waste characteristics affecting stability (physical and chemical). The design and construction methods conform to DMIRS guidelines for structural stability such as residual pit voids have been left as run-of-mine (ROM) where geotechnically stable.	• Landforms have already been constructed and there is limited information on 'as constructed' design. A suggested criterion is therefore: • Landforms are stable and show no significant slumping or failure of accessible constructed slopes or berms.	• Report on rehabilitation works at construction confirms safety and geotechnical guidelines have been met and sites constructed according to WAIO relevant procedure (not applicable to early era rehabilitation). • Rehabilitation Inspections confirm: • Earthworks have met final landform designs (not applicable to early era rehabilitation). • Landforms are stable.

Table 5.4 continues following page...

TABLE 5.4 Goldsworthy Northern Areas completion criteria

Criterion	Criterion objective	Domain	Criterion standard or milestone	Proposed variation to criterion for early era rehabilitation	Verification procedure
3.4 Surface Stability	The constructed surface is stable and showing no signs of significant erosion.	All	• Post-mining landforms have been designed and constructed taking into consideration the waste characteristics (physical and chemical). • Slope surfaces are stable, with no dispersive material on the surface; rock armouring is present as required and no areas are exposed to the risk of significant erosion which may be defined as having: • Channelised flow resulting in extensive active gullies; • Failure of banks, berms or bunds; and • Evidence of ongoing significant sheet erosion (including large accumulation of silt at base of slope, exposed subsoil, poor seedling establishment).	Landforms have already been constructed and there is limited information on 'as constructed' design. It is, therefore, suggested that the criterion focuses only on the outcomes i.e. that the landform is stable and does not have significant erosion, as defined in the criterion for recent rehabilitation.	• Report on landform construction methods (not applicable to early era rehabilitation), and any additional maintenance works undertaken. • Rehabilitation inspections (including undertaken on maintenance earthworks) confirm earthworks have met final landform designs (not applicable to early era rehabilitation). • Visual assessment and monitoring, taking into consideration the slope, available materials and vegetation cover and relevant research projects on surface stability of comparable rehabilitated landforms. • Rehabilitation monitoring results (including erosion monitoring) indicate gullies and rills are stabilising.
3.5 Landform Surface	Landform surface material promotes water infiltration and reduces erosion and crusting.	All (exc. mine voids and PAF material encapsulation OSAs)	Surface treatments (including ripping) undertaken to rehabilitated surfaces to maximise water infiltration, to reduce erosion potential and support establishment of vegetation.	• Not applicable. • Landforms have already been constructed and there is limited information on 'as constructed' design. Refer to outcome criteria in 3.4, 4.1 and 4.2.	• Report on landform construction methods. • Rehabilitation inspections confirm earthworks have met final landform designs.
4.1 Sustainability	Rehabilitation is sustainable, and the land capability and groundwater are suitable for the agreed end land use.	All where relevant	Monitoring, research data and site inspections indicate that the rehabilitation will be sustainable and will continue to fulfil rehabilitation objectives relating to the agreed final land use in terms of flora, vegetation, fauna, and surface and groundwater hydrology.	No variation proposed.	Documented in relevant monitoring and research reports; site inspections.

Table 5.4 continues following page...

TABLE 5.4 Goldsworthy Northern Areas completion criteria

Criterion	Criterion objective	Domain	Criterion standard or milestone	Proposed variation to criterion for early era rehabilitation	Verification procedure
4.2 Resilience	Vegetation is sustainable and resilient to likely impacts such as fire, drought and grazing (where applicable, if managed according to agreed guidelines)	All where relevant	• Monitoring and/or research results have shown that recruitment of native perennial species is occurring, or is likely to occur, on the site (e.g. evidence of flowering, fruiting, soil seed bank or second-generation seedlings). • Research trials in rehabilitation representative of the same age and technique have demonstrated its ability to regenerate following burning (in terms of key parameters such as cover, richness and density); rehabilitation has reached the age where plants are likely to tolerate fire or regenerate/reseed. • Monitoring has shown that the rehabilitation can survive one or more seasons of low rainfall.	Under development.	• Review of progress and performance of rehabilitation monitoring results, and related rehabilitation monitoring procedures. • Monitoring results reported in the AER. • Research findings from trials on representative rehabilitated areas investigating post-disturbance recovery of revegetation.
4.3 Growth Media	A suitable growth medium has been identified to facilitate plant establishment and growth	All where revegetation is planned	• Material placed on the outer surface of landforms takes into consideration the growth media characteristics required to support sustainable vegetation development. • The depth and characteristics of newly constructed landforms, surface soils and subsoils are suitable for plant growth in terms of their structure, water holding capacity and lack of materials that might affect plant growth or survival (i.e. they are suitable for establishing target vegetation communities and supporting the agreed final land use). • Soil stripping has been undertaken in accordance with the WAIO Rehabilitation Standards and Procedures. • Topsoil stockpiles have been managed following the WAIO Rehabilitation Standard and Procedures, and the relevant plans and databases have been prepared, updated and maintained. • Where available and appropriate to meet the landform design requirements, topsoil has been used to provide a suitable medium for plant establishment and a source of propagules.	• Not applicable. • Landforms have already been constructed and there is limited information on 'as constructed' design. Refer to outcome criteria in 3.4, 4.1 and 4.2.	• Topsoil reconciliation information available. • Review of baseline soil report (where available) and site waste characterisation report. • Report on landform construction methods. • Rehabilitation inspections confirm earthworks have met final landform designs. • Rehabilitation monitoring results provide feedback to determine suitability of growth medium.

Table 5.4 continues following page...

TABLE 5.4 Goldsworthy Northern Areas completion criteria

Criterion	Criterion objective	Domain	Criterion standard or milestone	Proposed variation to criterion for early era rehabilitation	Verification procedure
4.4 Provenance	Vegetation is locally endemic	All	All seeded/ selected plant species to be indigenous species of local provenance	Under development	• Site Rehabilitation Report including seed mix summary. • Seed Database. • Rehabilitation monitoring results.
4.5 Vegetation Development	Vegetation is suited to the agreed final land use	All with revegetation	• Established vegetative cover should be self-sustaining and similar to the surrounding undisturbed vegetation. • Monitoring of rehabilitated areas has been undertaken until it can be demonstrated that the landscape and vegetation are progressing towards a self-sustaining state. • Rehabilitation development stage density or cover target still to be developed. • The number of native perennial species shall be no less than the number recorded in comparable nearby vegetation that has not been disturbed. • Total native perennial vegetation cover to be ≥ 20%.	Under development	• Monitoring of vegetation reestablishment using WAIO Rehabilitation Monitoring Procedures. • Monitoring results reported in the AER. • Report on performance in relation to rehabilitation methods, using site inspection and rehabilitation monitoring sites to assess whether criteria have been met.
4.6 Weeds	Potential for rehabilitation to meet the agreed post-mining use is not limited by the presence of weeds	All areas with revegetation	• No Declared Pests (as defined under the Biosecurity and Agriculture Management Act 2007) are present in greater abundance than surrounding nearby vegetation. • Populations of environmental weeds have been monitored and controlled based on risk.	Under development	• Review of weed monitoring and control undertaken to ensure compliance with the WAIO Weed Management Procedure. • Report on weed monitoring and control records. • Measurement of weed abundance compared to representative reference sites, using cover or counts (as appropriate according to the species). • Monitoring and visual inspection of vegetation establishment and representative reference areas.

Table 5.4 continues following page...

TABLE 5.4 Goldsworthy Northern Areas completion criteria

Criterion	Criterion objective	Domain	Criterion standard or milestone	Proposed variation to criterion for early era rehabilitation	Verification procedure
4.7 Fauna Recolonisation	Revegetated areas provide suitable fauna habitat	All where opportunities exist	• As per the WAIO Rehabilitation Standard and Procedures include, where practical, the creation of habitat features similar to those found in the GNA Hub area prior to mining. Habitat creation initiatives include, but are not limited to, the following: • Creation of rock piles in OSAs and/or mine void areas to provide potential habitat opportunities for reptiles and mammals; • Return of vegetation debris, logs and rocks to areas which have been disturbed to provide microhabitats for recolonising fauna; • Creation of rocky cliff features, which may include small hollows and cracks suitable for reptiles and mammals; • Vegetation includes locally endemic species of known importance to fauna. • Signs of fauna recolonisation are apparent including (but not limited to) scats and presence of invertebrates; • Vertebrate pests (rabbit, dingo, donkey, goat and cat) have been controlled, where necessary.	• Landforms have already been constructed. A suggested criterion is therefore: • Signs of fauna recolonisation are apparent including (but not limited to) scats and presence of invertebrates. • Vertebrate pests (rabbit, dingo, donkey, goat and cat) have been controlled, where necessary.	• Rehabilitation inspections confirm earthworks have met final landform designs (not applicable to early era rehabilitation). • Fauna habitat assessment using site inspection and evaluation of vegetation monitoring results. • Vertebrate pest species have been controlled, as required.
5.1 Surface Water	Rehabilitation drainage patterns have been established and impacts on natural surface water flows are acceptable at key receptors	All where relevant	• There are no significant, physical off-site impacts at key receptors as a result of WAIO's operations. • Baseline conditions for surface water quality and flow regimes in Eel Creek, Egg Creek and the De Grey River have been maintained to an acceptable level. • Surface water quality should fall within guidelines for specific-end land use (e.g. stock watering requirements).	No variation proposed	• Documents reviewed and signed off as required. • Surface water sampling results from within Eel and Egg Creeks and the De Grey River indicate no significant impact from the GNA Hub. • Monitoring results reported in the AER and Annual Aquifer Review (as required). • Site inspection to verify no unplanned impacts on surrounding natural drainage patterns.

Table 5.4 continues following page...

TABLE 5.4 Goldsworthy Northern Areas completion criteria

Criterion	Criterion objective	Domain	Criterion standard or milestone	Proposed variation to criterion for early era rehabilitation	Verification procedure
5.2 Groundwater	Mining-related impacts on groundwater (levels, quality and soil moisture) have been minimised	All where relevant	• There are no significant, physical off-site impacts at key receptors as a result of WAIO's operations. • Baseline conditions for groundwater regime (levels and quality) have been maintained to an acceptable level. Water resource quality is managed within predetermined criteria based on ANZECC & ARMCANZ (2000a).	No variation proposed	• Groundwater monitoring results indicate no significant impact from the GNA Hub. • Monitoring results reported in the AER and Annual Aquifer Review (as required).
6.1 Infrastructure	Infrastructure has been decommissioned and removed where transfer to a third party is not agreed	All where infrastructure exists	Agreement has been reached with Government regarding whether any infrastructure is required to remain post-mine closure. Infrastructure not required has been removed (and recycled/reused where practicable) and the site rehabilitated.	No variation proposed	Site inspection and documentation of infrastructure removal and rehabilitation operations.
7.1 Contaminated Sites	Contaminated sites have been documented and addressed	All where relevant	All commitments relating to the identification and management of contaminated sites, as per *Contaminated Sites Act (2003)* have been fulfilled.	No variation proposed	Report documenting compliance with specific requirements
8.1 Land Management	Long-term management requirements have been addressed	All	At the time mine closure is considered complete, site land management requirements will be no greater than those of areas prior to mining (or comparable unmined areas); alternatively, where additional management actions are required, these will be identified in agreement with regulators, and WAIO will make adequate provisions so that this additional management can be undertaken.	No variation proposed	Reports into sustainability and long-term management requirements identified in the monitoring and research carried out as per Criterion 4.

Source: BHP (2018)

RISK MANAGEMENT

The physical and biological challenges to rehabilitation in the Pilbara include harsh temperatures, unpredictable rainfall, limited topsoil, hostile waste materials and poorly understood seed ecology (Risbey 2016).

As described above, BHP's approach is to refine completion criteria over time through research and monitoring. BHP uses the criteria framework to assist in identifying key knowledge gaps for each site which need to be addressed in order to develop more detailed criteria to support relinquishment. The knowledge gaps and associated research programs are prioritised through BHP's risk assessment process. The risk assessment process helps to identify those areas where there is a high potential for impact if a knowledge gap is not addressed. For example, in an instance where the local geology is known to contain erodible materials, having an inadequate understanding of the sources and quantities of competent waste at the outset of mining would be likely to have a significant impact on closure outcomes and the knowledge gap would be rated as a high priority.

The inclusion of planning and design criteria into the criteria framework prompts early consideration of the key issues that need to be addressed during these stages to enable outcome criteria to be achieved.

BHP employs an adaptive management approach to mine closure planning (Source: BHP (2018) Figure 5.5). As knowledge gaps are addressed during a mine's life and potential risks or impacts are better understood, BHP refines its management approach. In instances where potential impacts cannot be entirely avoided, the adaptive management approach allows for an evaluation of potential mitigation options and progressive refinement of preferred options over time to optimise eventual closure outcomes. As preferred options are honed, completion criteria are updated.

Source: BHP (2018)

FIGURE 5.5 BHP's adaptive management approach

GNA COMPLETION CRITERIA

The completion criteria for GNA are provided in Table 5 4. A brief description of selected criteria follows to illustrate how BHP has applied the principles described above, and some of the key challenges that have been encountered during the development and application of the criteria.

Criterion 3.1 Visual Amenity

A criterion for visual amenity is one that is difficult to apply numerical measures to as visual amenity is subjective. BHP's visual amenity criterion describes the outcomes as:

- Constructed landforms are compatible with that of local Pilbara landforms (objective)
- Landforms have been constructed to blend into the surrounding landscape (standard).

At GNA, BHP's landform design principles, which include preserving ridgelines and softening sharp edges, have achieved landforms that blend with natural landforms (Figure 5.6).

FIGURE 5.6 Cattle Gorge constructed landform (foreground), natural landform (background)

Sometimes optimal visual amenity outcomes are constrained by the physical nature of the materials available, tenement boundaries and proximity to water courses, particularly at older sites where closure considerations were not integrated into up front mine planning in the way that occurs now. In these instances, there may be a trade-off between visual amenity in terms of landform geometry and long-term landform stability (which may also have a visual impact). BHP's criterion recognises that there is a balance between short-term and long-term outcomes and acknowledges that there may be constraints to achieving a landform geometry with optimal visual outcomes within the criterion standard:

> *"Within the constraints imposed by aspects such as the physical nature of the materials available, tenement boundaries and proximity to water courses, landforms have been constructed to blend into the surrounding landscape"*

Criteria 3.2 to 3.5 Waste characterisation and landform stability

Criteria 3.2 to 3.5 have a strong focus on leading indicators as the outcomes of non-polluting and stable landforms are strongly influenced by whether problematic materials have been identified early and their placement has been incorporated in the mine plan such that impacts will be minimised.

The leading criteria mandate that:

- Materials characterisation is taken account of during landform designs
- An overburden storage plan be developed prior to commencement of ex-pit dumping activities
- Construction of landforms is in accordance with designs.

These criteria are all auditable and the criteria framework identifies the information that should be available to confirm conformance with the criteria (e.g. material characterisation reports and reports that confirm landforms have been constructed in accordance with designs).

In the case of the early era rehabilitation at GNA, it may be difficult to assess conformance with these leading indicators as there are limited records on materials characterisation and 'as constructed' designs. BHP, therefore, can only apply outcome criteria to these landforms.

The outcome criterion for erosion at GNA comprises a qualitative description of an acceptable outcome:

> *"Slope surfaces are stable, with no dispersive material on the surface; rock armouring is present as required; and no areas are exposed to the risk of significant erosion which may be defined as having:*
>
> - *Channelised flow resulting in extensive active gullies*
> - *Failure of banks, berms or bunds*
> - *Evidence of ongoing significant sheet erosion (including large accumulation of silt at base of slope, exposed subsoil, poor seedling establishment)".*

Erosion is a natural process and all the natural landforms in the Pilbara have been shaped by an erosion or deposition process. It is, therefore, a certainty that mine landforms will erode over time. The challenge in developing completion criteria is defining the acceptability of the erosion. To assist in further defining meaningful and relevant erosion criteria, BHP has contributed to a Pilbara Research Group project aimed at defining acceptable erosion rates for mine waste landform modelling in the Pilbara (Landloch 2018). In determining the impact of erosion and acceptable erosion rates, the project considered a wide range of factors including:

- Rates of soil formation
- Maintenance of soil quality, which may include considerations of:
  - Plant/crop productivity
  - Effective soil depth
  - Soil organic matter and nutrient stores
  - Rates of natural erosion in adjoining areas
  - Water quality impacts and
  - Potential for gully development.

The project recognised that different circumstances would apply to different sites and developed a risk matrix for assessing the risk of erosion from different landforms.

BHP broadly used guidance behind these criteria to design a concave slope landform at GNA with the available capping materials.

Criteria 4.2 to 4.6 Vegetation development and outcomes

There are a number of challenges in achieving revegetation of landforms in the Pilbara. These include:

- The Pilbara's arid climate and rainfall patterns which are characterised by isolated thunderstorms or cyclones during the summer months. These dramatic fluctuations in rainfall in the Pilbara mean that traditional revegetation methods, such as using nursery seedlings, are unlikely to succeed.
- Certain vegetation species seed only once every few years, which hinders annual revegetation works (BHP Billiton 2017).

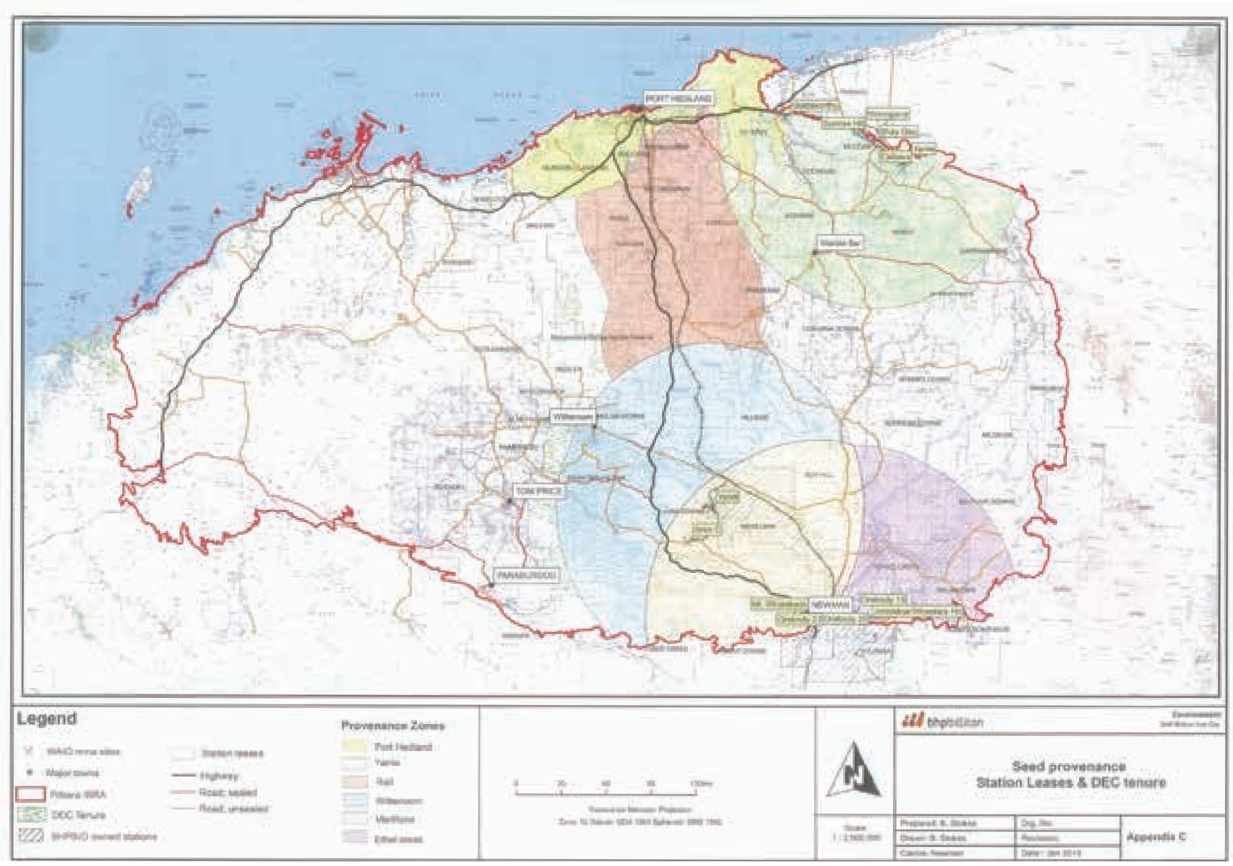
As part of its risk assessment program, BHP has recognised these challenges and has invested in research to improve its understanding of how best to use seed to revegetate the land. Over the past five years, the program has led to significant improvements in all facets of seed management, including identifying seed requirements, availability, viability, collection, storage, treatment, germination and species knowledge that informs rehabilitation programs (BHP Billiton 2017).

Research is ongoing and the Restoration Seed Bank Initiative, a five-year research partnership between BHP Billiton, BGPA and the University of Western Australia (UWA), is focused on resolving key seed propagation challenges such as dormancy and germination (Kaur *et al.* 2017; Lewandrowski *et al.* 2017b; Muñoz-Rojas *et al.* 2016a; Ritchie *et al.* 2017; Shackelford *et al.* 2013; Turner *et al.* 2017). The initiative is also aimed at the development of seed enablement technologies, new approaches to topsoil management and alternative growth media to overcome limitations to seedling establishment and plant growth (BHP Billiton 2017). It is expected that information arising from this initiative will result in future refinements to BHP's completion criteria and associated measurement framework.

As with the waste characterisation and landform stability criteria, the vegetation completion criteria for GNA comprise a mixture of leading and lagging indicators. The leading indicators focus on the identification, management and placement of a suitable growth medium and the selection of local provenance plant species.

Development of a seed provenance map in consultation with the Department of Parks and Wildlife (now Department of Biodiversity Conservation and Attractions) (Source: BHP Billiton (2013) Figure 5.7) enabled the provenance criterion to be included in BHP's criteria framework and provided a basis for auditing conformance with the criterion.

Photo courtesy: BHP



Source: BHP (2013)

FIGURE 5.7 Seed provenance map for Western Australian Iron Ore mine sites

The lagging criteria aim to describe the key aspects of a successful vegetation community at GNA including:

- Resilience to likely impacts such as fire, drought and grazing
- Self-sustaining system suitable for the agreed final land use
- The post-closure land use will not be limited by the presence of weeds.

BHP has been working with BGPA to develop a set of draft vegetation completion criteria for a general conservation end use (BGPA 2017). The criteria are designed to be science-based, quantifiable, attainable within a realistic time frame and acceptable to all stakeholders. The work used data collected from 360 transects over a six-year period in rehabilitated sites as well as analogue and post-fire unmined landscapes.

Based on two key guidance documents (EPA 2006; SERA 2017), BGPA developed a list of quantifiable vegetation parameters that assess desired rehabilitation attributes and are capable of supporting completion criteria (Table 5.5). The parameters were then ranked by considering the:

- Extent to which each parameter addressed the desired attribute
- Uniqueness of parameters, redundancy or co-variation among parameters
- Sensitivity of parameters to seasonal or successional drivers
- Sensitivity of parameters to the typical extent of changes to landforms, soils and hydrology that arise through mining
- Ease and accuracy of standard monitoring protocols for assessment
- Complementarity in assessment techniques
- Capacity to develop quantitative targets that unambiguously reflect the desired attribute.

The parameters with the highest scores (in bold in Table 5.5) were developed as criteria.

TABLE 5.5 Vegetation parameters

EPA (2006) Criteria	SERA (2017) Attribute	Class	Measurable parameter	Priority
9. Abundance or density **12. Canopy and keystone species** **16. Habitat diversity**	Community structure	Quantity	Cover	Highest
			Density	Medium
			Biomass	Low
		Structure	Bare areas	High
			Patchiness/ connectivity	Medium
			Strata	High
8. Species diversity **10. Genetic diversity** **11. Ecosystem diversity** **13. Effective weed control** **15. Animal diversity**	Species composition	Composition	Indigenous species (yes/no)	Highest
			Dominant species (yes/no)	Highest
			Native species richness	High
			Weeds (cover)	High
			Significant species/communities	High
			Floristic similarity / turnover	Medium
7. Self-sustaining and resilient	Ecosystem function	Reproduction	Flowering/fruiting	High
		Recruitment	Seedlings/survival	High
		Recovery	Recovery (e.g. from fire, drought)	High

Source: BGPA (2017)

To date, the following criteria have been adopted for the GNA site:

- All plant species to be locally indigenous species (sensu BGPA 2017) of local provenance
- The number of native perennial species shall be no less than the number recorded in comparable nearby vegetation that has not been disturbed
- Total native perennial vegetation cover to be ≥ 20%.

The total native perennial vegetation cover criterion is based on the minimum cover values observed in analogue survey data, which is 20%. In practice, BHP intends to develop a range of cover that reflects the range and variation of cover found in the reference system. The minimum analogue value was employed to avoid setting a standard that is higher than occurs in natural systems. As 20% is a base threshold, rehabilitation must be designed to exceed this cover. Comparison of perennial cover between rehabilitation and analogue sites shows that while the average values differ, the range of variation is similar between both. So, for all rehabilitation sites to exceed the minimum analogue threshold, including the worst performing, it is likely that maximum and average cover of rehabilitation sites will reflect the average and range observed in the natural system. This approach works best when initiating a collection of sites with the same criteria, rather than just one at a time, and only when aware that achieving the target involves aiming above the target. Also, if rehabilitation capability improved so that variation in cover outcomes is reduced, whether the average increases or not, the logic of this approach would no longer be valid.

Targets have yet to be developed for:

- Hummock grass cover
- Size of bare areas

Developing appropriate revegetation outcome criteria can occasionally have competing objectives for an area, depending on land use. For example, in the past BHP has consulted pastoral station owners about the control of the weed Kapok (*Aerva javanica*) and has been informed that it is one of the preferred feedstocks for cattle. Control is not favoured, as would be the case with a general conservation end land use criteria. However, it should be noted that pastoralists, as temporary land managers, do not hold authority to approve closure outcomes. Instead, this lies with the Pastoral Lands Board — a statutory authority established under Section 94 of the *Lands Administration Act 1997*. Issues such as these require further consideration of an appropriate criteria, acceptable to both landholders and other stakeholders.

Criterion 4.7 Fauna recolonisation

One of the challenges in developing criteria for fauna is that fauna presence can change temporally in response to many factors which may not be related to the quality of rehabilitation. BHP's fauna criterion is, therefore, weighted towards leading indicators that describe the conditions that would be expected to attract the return of fauna such as:

- Creation of habitat features such as rock piles
- Inclusion of locally endemic species of known importance to fauna in revegetation
- Control of vertebrate pests, where necessary.

The lagging indicator currently refers to signs of fauna recolonisation including (but not limited to) scats and presence of invertebrates.

At Cattle Gorge, both rock piles (Figure 5.8) and bat habitat (Figure 5.9) were incorporated into rehabilitation. Three different species of bats were acoustically recorded in the bat habitat structure three days after practical completion.

No Declared Pests (as defined under the *Biosecurity and Agriculture Management Act 2007*) are present in greater abundance than surrounding nearby vegetation.

FIGURE 5.8 Example of a rock pile at Goldsworthy Northern Areas

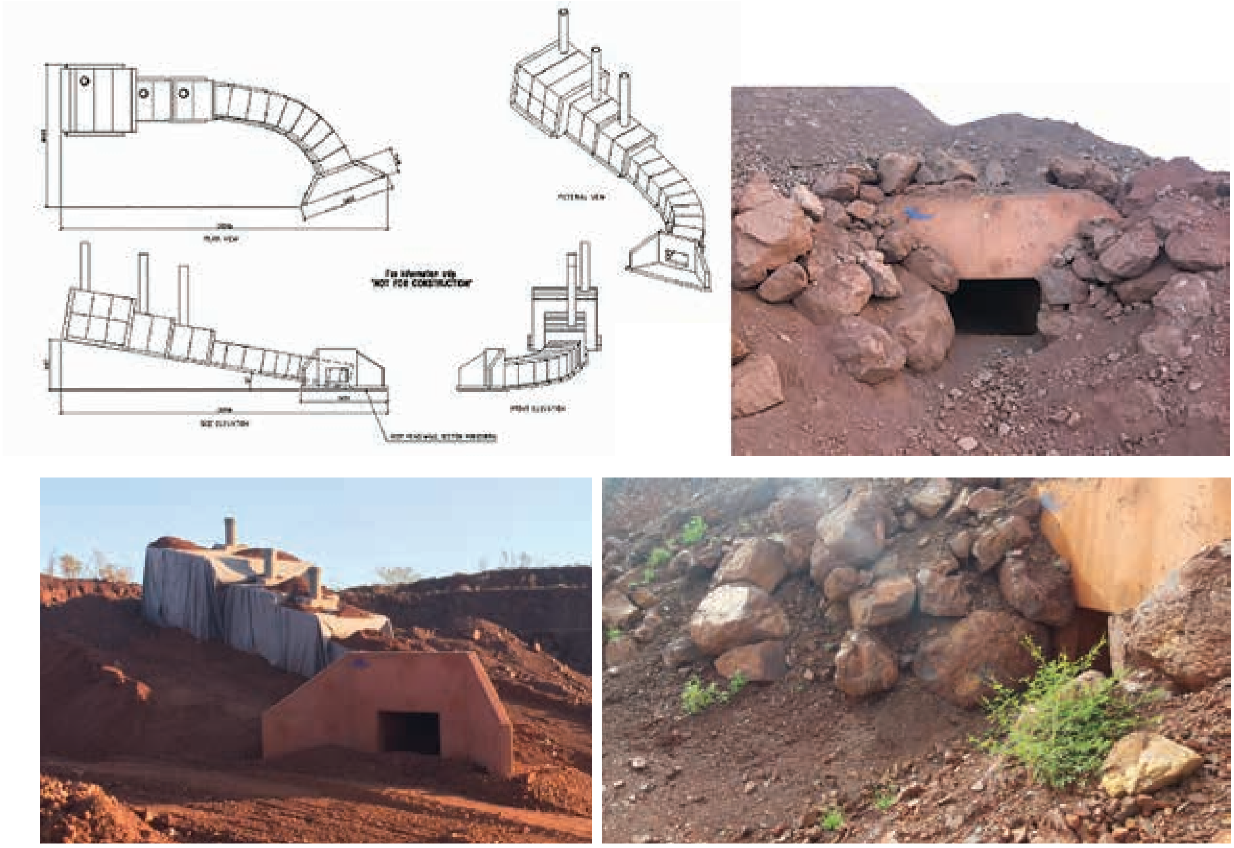


FIGURE 5.9 Bat habitat at Cattle Gorge

Criteria 5.1 and 5.2 water

Mining activities have the potential to change surface water and groundwater conditions. The key focus of BHP's water criteria is, therefore, on controlling changes so that there are no unacceptable impacts on key receptors.

One of the key lessons learned in using recognised generic standards for water quality is that in mineralised zones the background water quality may not meet these standards. At older sites where collection of baseline environmental data prior to development was not always rigorously undertaken, background data may need to be analysed to infer pre-mining conditions. This data may then be used as the basis for defining appropriate site-specific water quality completion criteria.

Monitoring and evaluation

BHP's criteria framework clearly outlines the information that will be used to verify achievement of each criterion and a monitoring and inspection program supports the collection of the information. The frequency and complexity of monitoring is risk based. For instance, where AMD risks have been identified, water quality is monitored to confirm predictions, update AMD modelling and allow for adaptive management in the case of unacceptable results (BHP 2017).

Revegetated landforms are monitored to establish the success of rehabilitation. Previous rehabilitation monitoring used Ecosystem Function Analysis. However, a review of the rehabilitation monitoring system was undertaken during 2011 and resulted in the establishment of an improved three-stage monitoring process:

- Rehabilitation Establishment Assessment (3 to 24 months of age) to provide feedback on the stability and erosion of rehabilitation areas and an assessment of vegetation establishment.
- Rehabilitation Development Monitoring comprising an in-depth assessment of rehabilitation involving Landscape Function Analysis, erosion monitoring and quadrat vegetation monitoring using existing monitoring transects. It is applied to maturing rehabilitated areas.
- Rehabilitation Landform Appraisal to provide a summary of the status of large scale rehabilitated landforms and areas not covered by Rehabilitation Development Monitoring (BHP 2018).

While changes in monitoring techniques can be problematic in terms of being able to compare the performance of rehabilitation from previous years, it is sometimes necessary to make changes to enable more meaningful and representative data to be collected. For example, BGPA (BGPA 2017) noted that species richness is scale-dependent, so vegetation monitoring transects have been modified from linear 50m x 1m plots to larger 50m x 50m plots to provide more representative data.

Remote sensing monitoring is being implemented, with annual research undertaken and monitoring methods modified to take advantage of new technologies. Remote methods can be applied to all phases of waste dump rehabilitation using laser scanning, LiDAR, aerial imagery, 3D reconstruction and multispectral analysis.

Future opportunities

Successful, effective and cost-efficient ecosystem recovery will more likely be achieved through targeted multidisciplinary research programs and knowledge transfer (Cross *et al.* 2018b). BHP will continue to explore collaborative research opportunities through avenues such as industry workshops, the Pilbara Rehabilitation Group and other industry partnerships such as the Global Innovation Linkages Project.

Further research, trials and analysis of monitoring data will facilitate the refinement of completion criteria. Advances in monitoring technologies are enabling efficient capture and analysis of data at a wider landscape scale including whole rehabilitation sites. The strongest promise of this technology is in its ability to track progress of rehabilitation against vegetation completion criteria on a broad scale. It is likely that hummock grass cover can also be effectively assessed using this technique and capacity to measure cover of other strata is also feasible. Adoption of these assessment tools would enable refinement of criteria relating to total vegetation cover, hummock cover and bare ground. It is likely that criteria relating to vertical structure could also be supported (BGPA 2017).

While the targeted end land use at GNA is appropriate to the current local socio-economic conditions, BHP regularly reviews these criteria. This takes into consideration any changes in stakeholder expectations that may involve re-purposing parcels of the mining area to an alternate end land use to better meet community expectations.

5.6.2 Mount Gibson Iron — Tallering Peak

Background

Mount Gibson Iron is a Perth-based independent iron ore producer established in 1996. Since 2002, it has been listed in Australian Stock Exchange and, over the financial year 2016-17, had a total sales revenue of AUD 173 million (Mount Gibson Iron 2017). Mount Gibson Iron currently operates three mine sites in Western Australia: Koolan Island (Kimberley coast), Extension Hill/Iron Hill and Tallering Peak, both in the Mid-West region (Source: Mount Gibson Iron (2017) Figure 5.10). Tallering Peak was the company's first mine to commence operations and the subject of this case study. Mining operations at Tallering Peak commenced in 2004 and ceased in 2014. The company is currently progressing mine closure to achieve site relinquishment.

The Tallering Peak mine is located 125km northeast of Geraldton and approximately 500km northeast of Perth. The closest population centre is Mullewa (63km south), with a population of 935. During operations, direct shipping ore (DSO) was transported by road to the Mullewa Rail transfer station, and then by rail to the Geraldton Port where it was stockpiled prior to being loaded onto ships and exported. The Tallering Peak Hematite Project consists of three entities of operation;

- Tallering Peak Iron Ore Mine;
- Mullewa Rail Transfer Station; and
- Hematite Storage and Loading Facilities at the Geraldton Port.

Mount Gibson's operations at the Geraldton Port are in accordance with an agreement with Mid-West Ports who, accordingly, dictate specifications for closure of the Hematite Storage and Loading Facilities. Therefore, the approved Mine Closure Plans (MCP) elaborated by Mount Gibson Iron include Tallering Peak Iron Ore Mine and the Mullewa Rail Transfer Station, but not the facilities at the Geraldton Port.

Source: Mount Gibson Iron (2017)

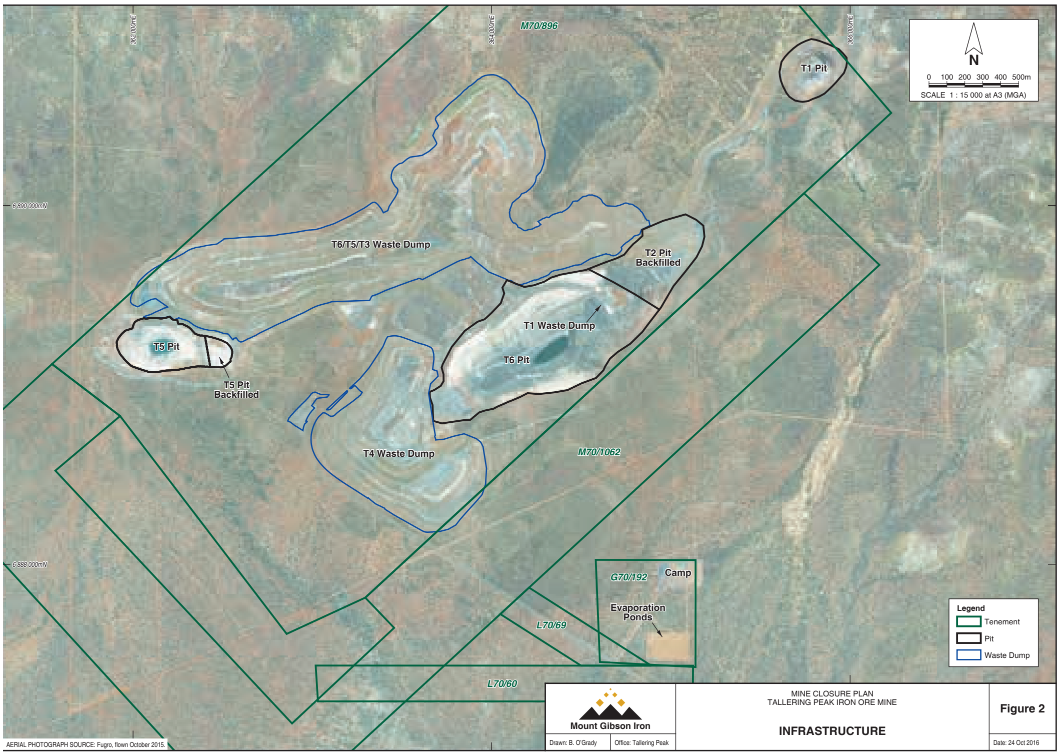
FIGURE 5.10 Location of Mount Gibson mining operations

The Tallering Peak Iron Ore mine site consists of three open pits: T6 (combining former T2, T2, T3, T6 and T4 pits), T5 and T1. The mine has three waste dumps: T2, T4 and a combined T3/T6/T5. Characteristics of pits, waste dumps and other key infrastructure are summarised in Table 5.6. A site plan of the Tallering Peak Iron Ore mine is depicted in Source: Mount Gibson Iron (2016) Figure 5.11.

The mining tenements coincide with the Wandina Station pastoral lease. An agreement with the pastoralist has determined what built infrastructure is retained.

TABLE 5.6 Key infrastructure at Tallering Peak Iron Ore mine

Infrastructure	Characteristics and rehabilitation	Area of disturbance (ha)
Open pits	• Backfilling has partially filled the T5 and T6 pits, as well as the northern T2 section of the main pit	81.2
Waste dumps	• T2 rehabilitated to pre-mining use (sloping hillside) • T4 annual Landscape Function Analysis (LFA) monitoring regime established in 2008. Currently rehabilitated. • T3/T5/T6 was progressively rehabilitated	230.5
ROM pad and crusher	• Decommissioned in late 2014. A stockpile of crushed low-grade fines and a stockpile of crushed low-grade lump hematite iron ore were removed from the load out area in 2017 and subsequently rehabilitated	18.8
Mullewa Rail Transfer Facility	• Under the operational control of the Ruvidini Registered Manager and left in place for possible future use	2.5
Offices and workshop	• Decommissioned in late 2014	8.4
Services (power, water, wastewater treatment)	• Decommissioned in late 2014/ early 2015	5.5
Explosives and diesel storage areas	• Decommissioned in late 2014	N/A
Transportation corridors	• Mine access roads were transferred to Wandina Station in 2015. • Mullewa Bypass Road was constructed by the Mullewa Shire prior to the opening of the mine and will remain under the City of Greater Geraldton's control post-mine closure	42.0
Accommodation village (Camp)	• Progressively decommissioned during late 2014. The fence around the village remains as an additional asset on the Tallering Station	3.8
Landfill	• Decommissioned and rehabilitated in early 2015	N/A



Source: Mount Gibson Iron (2016)

FIGURE 5.11 Tallering Peak iron ore mine site

ENVIRONMENTAL CONTEXT

Physical environment

Tallering Peak is part of the Tallering Range, which is an elevated feature rising 150m above the surrounding plains. The range is visible from the surrounding areas, with a picnic area and viewpoint located off the Carnarvon-Mullewa Road. However, public access to the viewpoint is now restricted via the Wandina Station homestead.

The Tallering Range is about 8km long and is composed of banded iron formations (BIF) which are especially resistant to erosion from long-term weathering (Mount Gibson Iron 2016). Each of the Tallering iron ore deposits occurs within a BIF unit, with the principal iron ore mineral being hematite (Fe_2O_3). The Mount Gibson Tallering Peak mine is based on the exploitation of one major and one minor massive hematite deposit in the northwest side of the Tallering Range.

The climate of the region is semi-arid, characterised by hot summers (mean monthly maximum temperature in January of 37°C) and mild winters (mean monthly maximum temperature in July of 19°C). The average annual rainfall, measured at Mullewa, is 337.4mm, with most of the rain concentrated in two wet seasons: May–August (frontal systems from the South-West) and January–March (summer thunderstorms and tropical lows).

Water bodies

There is no permanent surface water within the Tallering Peak mine site. However, a number of temporary streams are generated from flows off the Tallering range, chiefly on the Central and North ridges, forming the main catchment within the mining leases. These streams may provide recharge to the T5 borefield, as well as inflows into the Greenough River, which is proclaimed under the *Rights in Water and Irrigation Act 1914*.

Drilling campaigns and dewatering at the Tallering Peak mine showed that groundwater is located at depths greater than 25 m and that hydraulic connectivity is highly variable. The Mine held a licence for the abstraction and use of groundwater, prescribed under the *Rights in Water and Irrigation Act 1914*, although this was surrendered in 2015 because mining had ceased and water was no longer required. Water used for stock supply is generally fresh to slightly brackish and obtained from shallow depths in small quantities. A 200ML/yr groundwater license was granted to the previous (pastoral lease) owner. The current pastoral leaseholder is free to obtain their own 5C licence.

Flora

The Tallering Peak mine site comprises three main land systems (Tallering, Nerramyne and Tindelarra), each of which is associated with a certain characteristic vegetation community. Overall, vegetation communities are characterised by shrubs (e.g. *Acacia* shrubs), with greater plant diversity on the hill slopes (e.g. *Thryptomene decussata*, *Eriostemon sericeus*, *Eremophila* spp.) compared with flats and hill tops.

Over the life of mine (2004 to 2014), extensive surveys were conducted to identify and map significant flora species. Significant ecological communities were classified according to the Department of Environment and Conservation (DEC) Conservation Codes for Declared Rare and Priority Flora. These include two codes for Declared Rare Flora (DRF) — Presumed Extinct and Extant — and four Priority levels: P1, P2, P3 and P4. DRF species were not known to occur within the mine footprint nor surrounding the mine area. Four priority species were found, including P1: *Eremophila* sp. and *Hemigenia* sp.; P3: *Micromyrtus placoides* and *Prostanthera petrophila*.

Flora surveys carried out in 1994 and 1998 identified several weed species that were listed under the Agriculture and Related Resources Protection Act 1976 (WA). In accordance with Mount Gibson Iron's (MGI's) Weed Management Plan, weeds were controlled by occasional manual removal and spraying.

Fauna

Fauna surveys conducted in 1995, 2003 and 2012 in the Tallering area identified 101 vertebrate species, which consisted mainly of birds and reptiles, as well as few mammals, fish and amphibian species. A list of significant fauna species possibly present in the Tallering Peak mine area was compiled drawing from data available through the EPBC Act Protected Matters Search Tool (Australian Government 1999) and the DPaW (Department of Parks and Wildlife) database (Government of Western Australia 2016). Fourteen listed species of conservation significant vertebrate fauna had distributions that overlapped the mine site. However, due to lack of suitable habitat, 12 of the 14 species were considered unlikely to occur on site.

Surveys of invertebrate fauna conducted in 2008 and 2012 found 11 taxa, including spider, snail, millipede and slater species. Out of these 11, four were considered significant because of restricted ranges or listing under the *Wildlife Conservation Act 1950* (Government of Western Australia 1950).

A large population of the feral goat (*Capra hircus*) has been present at different times throughout the Wandina Pastoral lease, where the mine is located. Grazing of feral goats is known to be detrimental to the vegetation of the Tallering Peak area, including both the rehabilitated waste landforms and the analogue sites (see Mining Operations and Rehabilitation below).

PREVIOUS LAND USE

Tallering Peak Mine is located within the Shire of the City of Greater Geraldton. Formerly, the land where the mine site lies was part of the Wandina and Tallering Pastoral Stations where low-intensity grazing of rangeland goats was the primary land use. Subsequently, the station boundaries were modified by the previous lease holder, resulting in the Tallering Peak mine being contained within Wandina Station. Currently, the Wandina Station still exists under the granted tenements and, thus, goat grazing is able to occur within the tenement areas that are outside the mine's fenced perimeter (see Source: Mount Gibson Iron (2016) Figure 5.11). The current pastoral lease holder has re-stocked Wandina station with approximately 1000 cattle. Additional cattle will be added to the station lease in the coming months.

MINING OPERATIONS AND REHABILITATION

In 2003, Mount Gibson Iron commenced the development of iron ore hematite deposits in the Mid-West Region of Western Australia, with commencement of the Tallering Peak hematite project in February 2004 (Mount Gibson Iron 2016). The mine reached its target production rate of three-million tonnes per annum in the first quarter of the 2006 financial year.

The Tallering Peak mine ceased operations in May 2014 after 10 years of uninterrupted production, having generated over 25 million tonnes of iron ore over the lifetime of mining operations. Since the site was closed in September 2014, facilities have been decommissioned and removed in accordance with the mine closure and rehabilitation plan (Mount Gibson Iron 2016).

Progressive rehabilitation of the Mine was undertaken with the long-term aim '*to re-establish productive land surface that required minimal ongoing maintenance and management (i.e. stable and safe)*'. For this purpose, revegetation of disturbed areas was undertaken with a self-sustaining system of native species, with similar diversity, density and cover to the pre-mined ecosystem. As a result of progressive rehabilitation, the age of the vegetation in rehabilitated areas varies from one to 11 years old.

Closure tasks and final rehabilitation activities were completed in 2015 with rehabilitation of all areas disturbed by mining in the ten years of operation completed. The latest version of the Mine Closure Plan (MCP) was submitted in October 2016 and, along with the 2017 Annual Environment Report (AER), demonstrate that all important completion criteria were substantively met. However, after the annual report of 2017 was drafted, a dry spell of 160 days without rain affected the revegetation in the two younger waste landforms with reduced plant richness and density. Consequently, the completion criteria for vegetation cover were not met in all areas in 2017, despite these same areas having met the targets in 2016 and, additionally, despite similar drops in vegetation indicators in the analogue site due to the drought conditions.

Rehabilitation and associated completion criteria (e.g. species diversity) had appeared to be impacted by grazing pressure from goats in the rehabilitated waste landforms and, similarly, on the vegetation at the analogue sites. Grazing pressure was noted in the Ecosystem Function Analysis (EFA) reports of 2011 and 2012 as one of the potential factors hampering adequate vegetation growth towards achievement of completion criteria. Subsequent to the 2012 finding, around 400 goats were captured and moved out of the fenced mine area, which resulted in reduced grazing pressure and increased species diversity, as noted by the following annual EFA monitoring. These observations are relevant to the proposed post-mining land use and suggest careful management of goat grazing pressure will be necessary to sustain the condition of the rehabilitation sites in the longer term.

The full final relinquishment report was made by MGM in Jan 2019, based on agreed completion criteria to the Department of Mines, Industry Regulation and Safety (DMIRS) with a decision expected later in the year.

Methodology

The Mount Gibson Iron Tallering Peak case study was developed in two phases: data collection and analysis. The data collection phase consisted of first, a desktop review of mine closure plans (MCP); and second, a personal interview with two advisors at Mount Gibson Iron. The data analysis phases consisted of reviewing and summarising the information obtained to understand the process followed by Mount Gibson in the development of completion criteria for their Tallering Peak site.

Results

CLOSURE OBJECTIVES

According to *Guidelines for Preparing Mine Closure Plans* (DMP & EPA 2015), closure objectives for rehabilitated mines are to be safe, stable, non-polluting/non-contaminating and capable of sustaining an agreed post-mining land use; and for premises to be decommissioned and rehabilitated in an ecologically sustainable manner. Closure objectives proposed by mining companies must be site specific, consistent with post-mining land uses and defined for each of the various attributes present within the mine site.

The Mount Gibson Iron closure objectives, which are consistent with the above guidelines, can be summarised as follows:

- To ensure closure occurs in a timely (i.e. five to 12 years), orderly and cost-effective manner, and its associated costs are adequately represented in company accounts;
- To ensure accountability and availably of resources for the implementation of the closure plan;
- To define a suite of indicators that will demonstrate successful mine completion to the satisfaction of the Responsible Authority; and
- To engage with stakeholders and have their interest considered during the closure process.

CLOSURE GUIDELINES AND OBLIGATIONS

In the Tallering Peak mine, Mount Gibson Iron followed several other policies and guideline documents including:

- Guidelines for Preparing Mine Closure Plans (DMP & EPA 2015)
- Leading Practice Sustainable Development Program for the Mining Industry: Mine Closure and Completion (LPSDP 2006d)
- Leading Practice Sustainable Development Program for the Mining Industry: Mine Rehabilitation (LPSDP 2006e)
- Leading Practice Sustainable Development Program for the Mining Industry: Managing Acid and Metalliferous Drainage (LPSDP 2007)
- Safety Bund Walls around Abandoned Open Pit Mines DIR 1997)
- Contaminated Sites Management Series - Reporting of Known or Suspected Contaminated Sites (DEC 2006)
- Contaminated Sites Management Series - Potentially Contaminating Activities, industries and Land Uses (DEC 2004).

Numerous legal obligations also applied to the Tallering Peak mine, in accordance with tenement conditions and legislation. A summary of legal closure obligations is provided in Table 5.7. While the Tallering Peak Hematite Project was not under Ministerial Statement, it was a “prescribed premises”, thus triggering regulation under the *Environmental Protection Act 1986* (DER 2016).

TABLE 5.7 Legal closure obligations

Legislation	Section	Requirement relevant to closure
Aboriginal Heritage Act 1978	Part IV	Heritage sites are not to be altered, excavated, damaged, concealed or any portion of the site removed in anyway, unless granted via Section 16 or 18 under the Aboriginal Heritage Act 1978.
Contaminated Sites Act 2003	Part I, Section	The proponent or individuals are to report known or suspected areas of contaminated sites.
Contaminated Sites Regulations 2006	Part II (6)	
Contaminated Sites Act 2003	Part III, (23)	Sites classified as Contaminated –Remediation Required as described under the Contaminated Sites Act 2003 are to be remediated.
Environmental Protection (Controlled Waste) Regulations 2004	Part III, (6) (44)	Disposal of asbestos is to be separated, wrapped and labelled and disposed in accordance with Part III (6) (44)
		The proponent is to treat all products listed in schedule 1 of the Environmental Protection (Controlled Waste) Regulations 2004 as a controlled waste.
Environmental Protection Act 1986	Part V, (49)	Proponent shall not cause pollution or an unreasonable emission of noise, odour or electromagnetic radiation.
	Part V, (51)	The proponent shall not clear native vegetation without the relevant approval (e.g. clearing permit) in place.
Health Act 1911	Part IV (2) (87)	The proponent shall ensure (stagnant) pools, ponds, open ditches, and drains do not become offensive to the public or allow these areas to become prejudicial to human health.
Health Act 1911	Part IV (3) (95)	Removal of sewerage systems are to be conducted in accordance with Local Government Law and by a Licensed contractor Environmental Protection (Controlled Waste) Regulations 2004.
Environmental Protection (Controlled Waste) Regulations 2004	Part III	
Mining Act 1978	Part IV (84AA)	A mine closure plan is required to be approved by the Department and reviewed every three years, or as specified by the Department.
	Part III (1) (20) (3a)	Make safe all holes, pits, trenches and other disturbances on the surface of the land which are likely to endanger the safety of any person.
	Part III (1) (20) (3b)	Take all necessary steps to prevent fire.
Mining Regulations 1981	Part V (6) (97)	Avoid activity that obstructs any public thoroughfare or undermines any road, railway, dam or building in such manner as to endanger the public safety.
	Part V (6) (98)	The proponent shall not allow detritus, dirt, sludge, refuse, garbage, mine water or pollutant from the tenement to become an inconvenience to the holder of any other mining tenement or to the public, or in any way injure or obstruct any road or thoroughfare or any land used for agricultural purposes.
Mines Safety and Inspection Act 1994	Part IV (42)	The principal employer or manager of a mine must, in accordance with the regulations, notify the district inspector for the region in which the mine is situated before mining operations are suspended.
Soil and Land Conservation Act 1945	Part V (32)	The proponent shall take adequate precautions to prevent or control soil erosion, salinity or flooding; or the destruction, cutting down or injuring of any tree, shrub, grass or any other plant on land where land deregulation is occurring or likely to occur.
Wildlife Conservation Act 1950	(16 and 23F)	A person may not take for any purpose protected fauna or flora without a licence, or rare and endangered flora without the written consent of the Minister.

POST-MINING LAND USE

Land use at the Tallering Peak Hematite Project area will revert to pastoral grazing of native vegetation, once mining ends and rehabilitation is completed. Prior to mining, the area was under sheep, cattle and goat grazing, which still occurs within the tenement area adjacent to the mining domain (Wandina Station). Pastoral grazing was agreed for post-mining land use through a stakeholder consultation process involving the former Department of Mines and Petroleum (DMP, now DMIRS), Department of Environment and Conservation (DEC, now DBCA), local councils, residents and the mine site's previous pastoral lease holder.

Any improvements or infrastructure left on site post-mining, for the use of the land holder, would require advice from the Pastoral Land Board. A key condition is that the mine site will remain free from grazing until vegetation on rehabilitation areas reaches an agreed level of similarity with undisturbed vegetation at analogue sites. Analogue (control) sites were set within the tenement areas where grazing was ongoing, including three sites on the southern face of the Tallering Ridge and two on the northern face of a small nearby ridge.

These comparative sites were used as references for the definition of completion criteria. All sites were analysed using EFA annually (at the same time each year e.g. spring) to monitor the progress of the rehabilitation program.

Other options for future land use that have been considered previously include tourism and nature conservation. The Mullewa Shire suggested developing the rehabilitated mine into a tourist attraction, yet the pastoral landholder rejected the idea and proposed to direct tourists to the existing operation on Wandina Station. The Tallering Range hosts several priority species of native plants for conservation, yet nature conservation was not pursued as a post mining land use as this would result in the permanent removal of the pastoralists from the site. In addition, Mount Gibson Iron did not receive any requests from the Department of Parks and Wildlife (now DBCA) to add the Tallering Range and rehabilitated mine site to the conservation estate.

Completion criteria development

CLOSURE DOMAINS

To facilitate the process of mine closure planning, the Tallering Peak mine site was divided into 'closure domains', which are defined as areas of similar characteristics. The four separate domains included open pits, waste dumps, industrial-plant and infrastructure, and rail transfer facility. In general, open pits were managed for acid contamination or back-filled, waste dumps were rehabilitated with native vegetation for grazing and the remaining two domains were left as is or decommissioned and rehabilitated with native vegetation not-for-grazing (Table 5.8). Each domain was subdivided into 'elements' that outline the specific areas requiring management for closure. For example, within the 'waste dump' domain, each of the three waste dumps (T2, T4 and T3/T6/T5) constitute a separate element. Likewise, within the 'industrial-plant and infrastructure' domain, distinct elements include workshops, explosive storage areas, roads and accommodation village, among others. Given the agreed post-mining land use of pastoralism, final configurations for each closure element were developed, as summarised in Table 5.8.

TABLE 5.8 Rehabilitation actions by domain and element

Domain	Element	Rehabilitation action
Open pits	T2 pit	Backfill T2 and rehabilitate
	T6 pit	Leave open and establish abandonment bund around the pit
Waste dump	T4 Waste dump	Rehabilitate
Plant and infrastructure	Workshops	Decommission, reuse/recycle where possible and rehabilitate
	Services	Retain elements (bores, pipes) for pastoral use, rehabilitate others
Rail transfer facility	Workshop	Workshop Decommission, reuse/recycle where possible and rehabilitate to required post-mining land use

COMPLETION CRITERIA

Mount Gibson's methods for establishing completion criteria are in line with guidelines provided by DMP and EPA (2015). These state that completion criteria should follow the S.M.A.R.T. principle and be Specific, Measurable, Achievable, Relevant and Time-bound. Thus, the Tallering Peak MCP defines completion criteria that are specifically tailored in consideration of the mine's i) post-mining land use; ii) analogue sites; iii) closure domains; and iv) closure objectives.

In each version of the Mine Closure Plan (MCP), completion criteria were defined in further detail, from indicative criteria to final criteria. Detail on each criterion was provided in response to the regulators' request.

The Tallering Peak MCP defines closure objectives for the following 12 attributes:

- Compliance
- Closure Administration
- Access and Security
- Environmental Monitoring
- Landform Stability
- Flora and Fauna
- Surface Water
- Groundwater
- Acid Mine Drainage:
- Site Contamination
- Air Quality, Noise and Vibration
- Infrastructure.

For each of the 12 attributes (and corresponding closure objective) at least one indicative completion criterion and one completion criterion are defined. Some attributes, like flora and fauna, have more than one criterion. An example of the latest completion criteria, as per Mount Gibson's October 2016 MCP, is presented in Table 5.9.

Photo courtesy: Mount Gibson Iron

TABLE 5.9 Examples of Tallering Peak completion criteria

Closure objectives	Indicative completion criteria	Completion criteria	Measurement tools	Applicable closure domains
Landform Stability: To achieve a final landform that remains stable long term and meets the end land use objectives	Concept level engineering designs and specifications for landforms, which will not be prone to slumping, mass movement or significant erosion	Demonstrated landform stability under representative climatic conditions	Visual monitoring / regular inspection of landform stability during the post closure monitoring and maintenance period. Analysis of site-specific meteorological data to demonstrate representative climatic conditions have occurred since landforms were constructed	Waste dump
Flora and Fauna: To establish a self-sustaining ecosystem commensurate with pastoral land use	Vegetation composition on rehabilitated areas is representative of the pastoral land use ecosystem and vegetation community requirements	Vegetation composition on rehabilitated areas is representative of the pastoral land use ecosystem and vegetation community requirements (diversity ≥ 75%, cover ≥ 15%, stems / hectare ≥ 50% and declared weed cover ≤ 10% of comparative analogues). (Government of Western Australia 2007)	Annual quantitative survey of vegetation through Ecosystem Function Analysis (EFA) in rehabilitated areas in comparison to local control survey sites	All
Access and Security	All roads (apart from those retained for station owner use) rehabilitated with natural drainage lines re-established	All roads (apart from those retained for station owner use) rehabilitated with natural drainage lines re-established	Rehabilitation records. Stakeholder consultation records identifying agreement on infrastructure retention.	Infrastructure
Surface Water Management: To maintain the natural quality and quantity of surface water to ensure that existing and potential uses, including ecosystem maintenance are protected consistent with the ANZECC &ARMCANZ 2000a water quality guidelines	Measurements of pH, EC and TSS in runoff leaving the mine site are consistent with measurements in Bangemall Creek or the Greenough River for the same flow event	Interpretation of measurements of pH, EC and TSS in runoff leaving the mine site to check consistency with measurements in Bangemall Creek or the Greenough River for the same flow event	Surface water analysis using accredited laboratory analysis and field measurements during the post-closure monitoring and maintenance period	All
Acid Mine Drainage: To minimise the potential for acid mine drainage (AMD) from the waste rock dumps	Appropriate waste dump designs generated to minimise the potential for AMD	Appropriate records to demonstrate that approved designs have been implemented	Visual assessment of area for any signs of AMD (seepage staining, iron precipitates, vegetation die off) during post-closure monitoring and maintenance period	Waste dump
Air Quality, Noise and Vibration: To manage dust emissions to ensure potential impacts on vegetation are minimised	Depositional dust levels post closure return to pre-mining levels	Depositional dust levels post closure return to pre-mining levels	Depositional dust records (post closure (<5 years) and analogue)	All
Infrastructure: No infrastructure left on site unless agreed to by regulators, key stakeholders and post-mining pastoral lease holder	Stakeholder consultation with regulators, key stakeholders and post-mining pastoral lease holder regarding remaining infrastructure	Stakeholder consultation records identify agreement with regulators, key stakeholders and pastoral lease holder regarding remaining infrastructure	Stakeholder consultation records. Copy of formal approval letter from Pastoral Lands Board to station lease holder	Infrastructure

Monitoring and evaluation

SOIL AND WASTE MATERIAL CHARACTERISATION

The soils in the Tallering Peak mine site vary between land systems in the following manner:

- Tallering Land System: lithosols, shallow sands and loams; slightly acidic (pH ranging from 5.5 to 6.0).
- Nerramyne Land System: gravelly loamy sands (east of the ridge); siliceous sands or sandy clay-loams over granite (on the gravelly plains); and clayey or loamy sand over clays (in the drainage zone).
- Tindelarra Land System: sandy clay-loams and red earths (in the wash plains); duplex or clay over hardpan (alluvial plains); and hardpan loams over granite or hardpan (surfaced plains).

Soil stability and erodibility on waste rock landforms were assessed by a consultant through the annual Ecosystem Function Analysis (EFA) monitoring since 2008. The reports indicated that erosion was minimal, rock cover was good and all the EFA indices had achieved completion criteria targets. However, some erosion appeared on the T3/T5/T6 waste dump and this was subsequently repaired by a specialist earthworks contractor. All waste dumps were shaped and prepared for rehabilitation. Reclaimed topsoil was applied to all waste dumps.

FLORA AND VEGETATION

Mount Gibson Iron completed a series of surveys (1992–2013) and rehabilitation trials (2008–2012), which served to identify the most effective rehabilitation practices and define achievable closure objectives specific to the Tallering Peak site. The challenges to vegetation rehabilitation include limited topsoil, landform instability, low rainfall and soil erosion (T. Collie, pers. comm. Oct 2018).

Native habitat and vegetation surveys were carried out prior to mining, between 1992 and 2000. The aims of these baseline surveys were to a) identify flora of conservation significance; and b) collect data to characterise the native vegetation of the area. The information obtained from these baseline surveys were used to determine the seed mix for rehabilitation of Tallering Peak mine site. During mine operations, further flora surveys were completed between 2006 and 2013, to identify locations of conservation significant flora species within the Tallering Peak region.

Landscape Function Analysis (LFA) and vegetation monitoring were conducted on a rehabilitation trial, first established on the T4 waste landform (2008–2011), and then also applied to T3/T4/T6 waste dump in 2012. It has been repeated on all dumps in every year since. The purpose of the trial was to analyse soil chemistry, test rehabilitation techniques for supporting vegetation growth and determine optimal seed mix for rehabilitation.

LFA monitoring revealed that levels of all three LFA indices (stability, infiltration and nutrient cycling) were between 54% and 72% of levels at the analogue sites. Based on these results, and the fact that analogue sites benefit from established vegetation, it was understood that high levels of LFA indices (i.e. >75%) would not be attainable in the rehabilitated areas. Thus, a target was set whereby waste landforms would have a median LFA stability rating of ≥50%, infiltration rating of ≥20% and nutrient cycling rating of ≥15% and compare favourably with natural analogue site trends.

Results of the flora and vegetation surveys served to design the seed mix around the dominant species, as well as the likely best availability of seed. The seed list was updated based on the success of the species that established in rehabilitation (identified from the early vegetation monitoring). Consequently, rehabilitated vegetation tended to be comprised of common native species that were able to establish in the surface cover conditions that characterised the waste dumps.

HERITAGE

Archaeological and ethnographic surveys were undertaken in 1992, with further heritage surveys carried out in 2002. Information obtained during these surveys served to define Aboriginal Heritage Exclusion Zones that are in place on the mine. In 2009, further surveys were completed ahead of an intensive exploration drilling program. In 2012, archaeological and ethnographic surveys were undertaken to enable submission of an application under the *Aboriginal Heritage Act 1972* for exploration drilling in the T1 area and the issue of Ministerial consent for the ground disturbances. All heritage surveys at the Tallering Peak mine site were reported in accordance with the *Aboriginal Heritage Act 1972* (Government of Western Australia 1972).

There are no known sites of European heritage significance on or near the mine site.

Risk analysis

Risk analysis at the Tallering Peak mine site was developed taking into consideration pastoralism as the post-mining land use and incorporating relevant closure issues identified by stakeholders. Risk analysis was done following the principles outlined in the AS/NZ ISO 31000:2009 Risk Management and Australian Standard IS014001 (ISO 2015).

As the life-of-mine progressed, the risk analysis in each version of the MCP was reviewed based on updated risks and mitigation measures across the site. The 2014 risk analysis was updated in 2016, based on post-closure monitoring information. ‘Post-closure’ refers to the window after finalisation of closure activity but before closure is attained. The 2016 update resulted in the reclassification of 'groundwater contamination from acid in T5 pit' from unknown risk to low risk because of evidence of the pit water operating as an evaporative sink. Moreover, several items were downgraded from high residual risk to low risk level, including erosion of dumps and erosion of backfilled pits.

Photo courtesy: Mount Gibson Iron

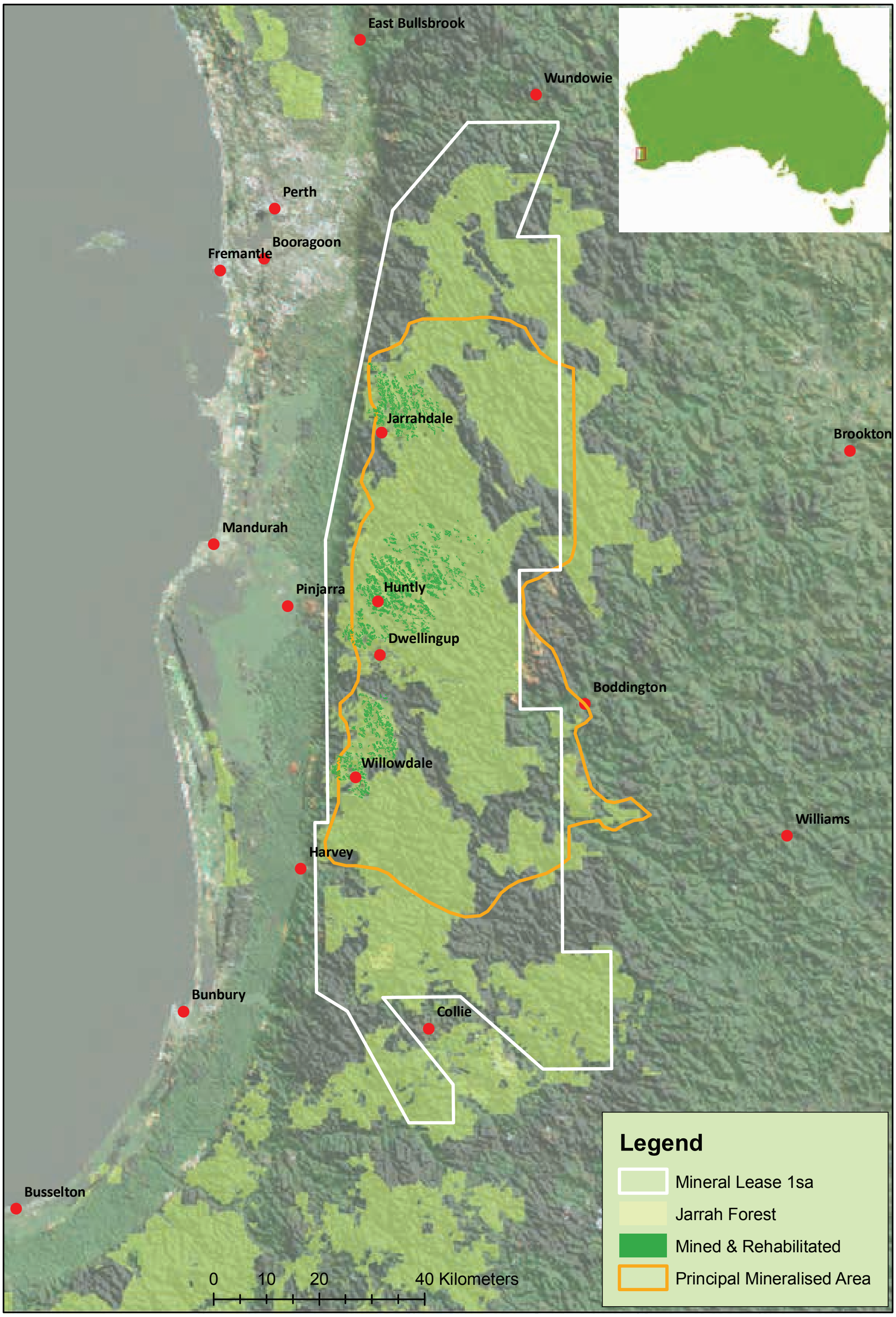
Photo courtesy: Alcoa

5.6.3 Alcoa — Northern Jarrah Forest

Background

Alcoa's mining operations in the Northern Jarrah Forest in south-west Western Australia comprise the Huntly and Willowdale bauxite mines, located approximately 100km south-east of Perth (Source: Alcoa (2018c) Figure 5.12). Established in 1976, Huntly is currently the world's second largest bauxite mine, supplying 26 million tonnes of bauxite in 2016 (Alcoa 2018a). Willowdale mine was established in 1984 and in 2017 supplied 10 million tonnes of bauxite (Alcoa 2018b). Across Huntly and Willowdale, approximately 600 hectares of mined land is rehabilitated each year, with the long-term objective of establishing a self-sustaining jarrah forest ecosystem (Koch 2007a). A third mine at Jarrahdale ceased operations in 1998, having been open for 35 years and producing 160 million tonnes of bauxite ore in its lifetime. The closure of Jarrahdale mine, including decommissioning of infrastructure and final rehabilitation of haul roads and pits, was completed in 2001 (Mining Atlas 2018).

Alcoa's mining operations are overseen by the Mining and Management Program Liaison Group (MMPLG), an interagency government group responsible for the review of mine plans on a rolling annual basis. The MMPLG also provided oversight for the development and implementation in the 1990s of Alcoa's completion criteria for its bauxite mine rehabilitation (Elliott *et al.* 1996). This included a process of assessment leading to the issuing of Certificates of Acceptance for areas that have met all appropriate criteria (Alcoa 2018d). The completion criteria are reviewed on a periodic basis, with the latest revision completed in 2015.



Source: Alcoa (2018c)

FIGURE 5.12 Map of Alcoa's mineral lease ML1SA

ENVIRONMENTAL CONTEXT

The Northern Jarrah Forest is part of the South-West Botanical District, characterised by high plant and animal diversity and comprised of more than 780 native plant species, 235 vertebrate terrestrial species and invertebrates species in the order of tens of thousands (Grant & Koch 2007). The vegetation is defined as open forest, with its overstorey dominated by jarrah (*Eucalyptus marginata*) and marri (*Corymbia calophylla*). The midstorey includes bull banksia (*Banksia grandis*) and snottygobble (*Persoonia longifolia*) and is typically sparse, while a diverse understorey is dominated by four native plant families: Fabaceace, Proteaceae, Myrtaceae and Mimosaceae (Bell & Heddle 1989).

The climate is typically Mediterranean, characterised by hot, dry summers and cool, wet winters. Summer droughts are common, often lasting up to four to six months (Gardner & Bell 2007). Occasional cyclones during hot periods may bring rain, but also thunderstorms and lightning, thus greatly increasing the risk of wildfires. The average rainfall in the region of bauxite mining is between 900 and 1,300 mm per year, 60% of which falls between June and August.

PREVIOUS LAND USE

Most of the Northern Jarrah Forest lies within State Forest which has been managed for multiple uses including water catchment, conservation, timber production and recreation (Nichols *et al.* 2005). The forest was selectively logged prior to mining activity (Grant & Koch 2007).

MINING OPERATIONS AND REHABILITATION

Alcoa's bauxite mining occurs in shallow 'pods', averaging 4 to 5m deep and is typically located less than one metre below the soil surface (Grant & Gardner 2005). The mine pits range in size from 2ha to 60ha, with an average size of 10ha. Each mine pit is prepared by harvesting trees for timber, clearing the mid and understorey vegetation, salvaging the topsoil (upper 15cm) and underlying overburden (10 to 80cm deep) layers for use in rehabilitation (Grant 2006). Bauxite extraction involves blasting of an indurated layer where present, which is removed together with the friable material below.

Mine pits are rehabilitated. The first step consists of reshaping or landscaping the mine pit by battering down the pit faces to blend with the surrounding topography, along with deep ripping of compacted areas to 1.5m depth to facilitate percolation and root exploration. Overburden and topsoil materials are returned in sequence and, finally, a second shallow (0.8m) ripping along the contour assists in reducing erosion, promoting rainfall infiltration and preparing a seedbed for applied seed. Because topsoil contains a seedbank important for plant establishment, and is enriched in organic matter, nutrients and microorganisms, it is immediately transferred from stripping areas to rehabilitate nearby pits whenever possible. Logs and rocks are also returned to provide habitat for native fauna. Seed of more than 60 species is collected from the forest ensuring local provenance and applied within a week of contour ripping to supplement plant species established from the soil seedbank. All soil return, contour ripping and seeding is carried out during the drier summer months. Plant species that are difficult to return via topsoil or collected seed are propagated under nursery conditions and seedlings are planted during the winter months. A one-off application of fertiliser by helicopter occurs in the second spring after establishment, to replace soil nutrients lost in the clearing and mining steps and to encourage early plant growth.

Rehabilitation is a progressive operation, with approximately 600 a of forest cleared for mining and subsequently rehabilitated each year. Approximately 20,000ha of rehabilitation has been established since the first rehabilitation was completed in 1966. An example of Alcoa's rehabilitation is illustrated in (Source: Grant and Gardner (2005)) Figure 5.13. The images depict an area of the jarrah forest where, after bauxite mining, all rehabilitation objectives were met.

Source: Grant and Gardner (2005)

FIGURE 5.13 Mining at Alcoa's Huntly operation in 1980 (left) and after restoration in 2001 (right)

Methodology

Research for this case study was split into two phases. Firstly, a document review was completed, primarily involving internal reports supplied by Alcoa and regulatory documents. Second, a semi-structured interview was conducted in person. The aim of the interview was to fill knowledge gaps evident after the document review or to provide more detail on particular emergent themes. Results were synthesised into a report addressing the research objectives outlined above.

Results

REHABILITATION OBJECTIVES

The rehabilitation objective is '… to establish a stable, self-regenerating jarrah forest ecosystem, planned to enhance or maintain water, timber, recreation, conservation and/or other nominated forest values'. Rehabilitation objectives and, consequentially, completion criteria are based on the following five key principles:

- **Land use:** rehabilitated areas meet the land use objectives
- **Integrated landscape:** rehabilitated areas are integrated into the landscape
- **Sustainable growth and management:** rehabilitated areas exhibit sustained plant growth and ecosystem development
- **Resilience:** rehabilitated vegetation is as resilient as jarrah forest to disturbances such as drought and fire
- **Integrated management:** rehabilitated areas can be integrated into broader forest management plans.

POST-MINING LAND USE

The selected post-mining land use must be compatible with surrounding forest values and uses, protect biodiversity, meet community expectations, and fulfil all governmental regulation requirements (Gardner & Bell 2007). Occasionally, certain sites may have elevated historical, recreational or other values where closure objectives differ from those outlined in the standard completion criteria. In these cases, specific area management plans are developed by Alcoa and subsequently approved by the MMPLG (Alcoa 2015).

COMPLETION CRITERIA DEVELOPMENT: HISTORY

Prior to 1971, rehabilitation at the Jarrahdale mine consisted of plantations of either Pinus or Eucalyptus species native to the eastern states of Australia which were chosen for their resistance to 'dieback' disease, caused by the soil-borne pathogen *Phytophthora cinnamomi*. Subsequent efforts up to 1977 introduced ground preparation treatments (e.g. landscaping), while rehabilitation in the period 1978-1987 broadened the range of native understorey species. The time period prior to 1988 is known as the Early Era, during which the key objective was to establish a functioning and self-sustaining eucalypt forest. Completion criteria for Early Era rehabilitation were developed retrospectively and approved in 2002. The criteria were based on assessments at later stages of development and include rehabilitated using outdated methods (Nichols *et al.* 2005).

From 1998 onwards (the period known as the 'Current Era'), rehabilitation has been undertaken using only species native to jarrah forest, including the canopy dominants jarrah (*Eucalyptus marginata*) and marri (*Corymbia calophylla*) trees. The objective for the Current Era is to restore a self-sustaining jarrah forest ecosystem planned to enhance or maintain water, timber, recreation, conservation and/or other nominated forest values (Nichols *et al.* 2005). The specific conservation goal is to encourage the development of floral, faunal and soil characteristics similar to those of the indigenous jarrah forest ecosystem. Completion criteria for the Current Era include areas rehabilitated using methods as summarised in Standish *et al.* (2015).

Given the evolution of rehabilitation practices and procedures over time, Alcoa's rehabilitation areas are assessed against a different set of criteria depending on the year when rehabilitation was established. For the 1998–2004 period, criteria were approved in 1998. Rehabilitation between 2005 and 2015 had criteria reviewed and approved by MMPLG in 2007. The latest criteria are defined in the 2015 revision of Alcoa's rehabilitation program (Alcoa 2015) and comprise the period from 2016 until today. Both Current and Early Era completion criteria are required to be reviewed at five-yearly intervals (Nichols *et al.* 2005).

Photo courtesy: Alcoa

COMPLETION CRITERIA DEVELOPMENT: ROLE OF RESEARCH

The definition, achievement and monitoring of closure objectives and specific completion criteria has been possible as a result of Alcoa's long-standing and comprehensive research program, which started in the early 1980s. Since then, Alcoa's Environmental Research Group has collaborated with universities, CSIRO, Government departments and individual experts on a range of aspects related to ecosystem establishment and recovery in rehabilitated areas (Alcoa 2015). Key research areas have included the re-establishment of flora and fauna diversity, successional processes, nutrient cycling, soil development and resilience to disturbance (Nichols *et al.* 2005). Further detail regarding these and other research questions can be found in numerous studies available in the published literature including a special issue of the journal Restoration Ecology that summarised two decades of research (Volume 15(S4), 2007) and other publications (e.g. Bell 2001; Bell & Heddle 1989; Brennan 2003; Gardner & Bell 2007; Grant 2003; Grant & Koch 2007; Grant *et al.* 1997; Jasper 2007; Koch 2007a; Nichols 1998; Nichols *et al.* 2005; Nichols & Nichols 2003; Smith *et al.* 2004a; Smith *et al.* 2000; Ward *et al.* 1990; Ward *et al.* 1993).

Alcoa's commitment to biodiversity restoration in the jarrah forest has been driven by the need to preserve the interest of the local community, as well as those of the natural environment (Grant & Gardner 2005). Such commitment has led Alcoa's research and rehabilitation achievements to be recognised by numerous national and international awards (Grant & Gardner 2005). Among others, outstanding awards include the Western Australian Department of Mines and Petroleum Golden Gecko Award (2007 and 2002), Society for Ecological Restoration International Award (2003) and the United Nations Environmental Program Global 500 Honour Roll (2003), which made Alcoa of Australia the first mining company worldwide to be recognised for its rehabilitation excellence (Alcoa 2018d).

COMPLETION CRITERIA DEVELOPMENT: IN PRACTICE

Alcoa has developed a suite of internal standards, including environmental policy, restoration objectives and completion criteria, that exceed regulatory requirements (Grant & Gardner 2005). These standards are based on extensive research and development activities, aimed at returning biodiversity to the mined areas. Some of these experiences are unique to Alcoa, while others have the potential to be applied to mining operations elsewhere.

The company follows a set of internal guidelines in the development of completion criteria.

First, criteria should include both *prescriptive* and *performance* indicators. The former confirm that actions have been carried out, while the latter refer to attainment of agreed standards or milestones. This distinction is similar to that made by risk management frameworks (ICMM 2012) distinguishing between *leading* (measuring circumstances preceding an event) and *lagging* indicators (measuring final outcomes).

Second, completion criteria are based on the five key principles outlined in Section 5.6.3 'Rehabilitation objectives'. Third, Alcoa divides its completion criteria into four time-bound stages. This approach reflects that certain criteria need to be met at early stages of rehabilitation, while others become relevant later and, therefore, depend on the successful completion of previous criteria. For example, correct re-landscaping (i.e. earthworks) needs to be achieved as a first step, which will then allow adequate plant growth and fauna return. By contrast, poorly-conducted earthworks may lead to excessive erosion due to water flows, thus preventing the desired rehabilitation outcomes. The four stages for the definition of completion criteria and their relevant aspects are as follows:

1. **Planning:** land use and management priority; existing environment; sustainable growth and development; integrated landscape; integrated management.
2. **Rehabilitation earthworks (landform and soil re-establishment):** integrated landscape; sustainable growth and development; catchment protection.
3. **Early establishment (first 5 years):** vegetation establishment; resilience of vegetation to weeds, dieback, other forest diseases, fire, insects and drought.
4. **Vegetation (12 years and older):** resilience of vegetation; land use (including timber production).

RISK MANAGEMENT

Alcoa manages short and longer-term risks of failure to meet completion criteria. In the short term, the staged approach to setting and achieving completion criteria facilitates the management of risk. Monitoring (as described in the next section) serves to identify whether remedial action may be necessary and, if so, the extent of reworking required. In the longer term, completion criteria are based on research and monitoring to determine what outcomes may or may not be achievable. In this way, completion criteria have become more complex while managing risk of failure.

MONITORING

As part of the rehabilitation certification process, completed rehabilitation is assessed and monitored at several stages. The first evaluation is carried out at the end of the rehabilitation season and is aimed at assessing criteria related to landform earthworks and ground preparation, soil return and seeding (Table 5.10). Second, early monitoring undertaken towards the end of the first year is aimed at ensuring an adequate density of trees for future timber production and other forest values, establishment of leguminous understorey species important for long-term soil nitrogen supply, and the presence of any weed infestations. Any erosion arising from winter rains is also identified at this stage. This early monitoring step enables aspects that do not meet specifications to be quickly addressed, triggering remedial earthworks, infill planting or reseeding (Source: Grant (2006, p. 30) Figure 5.14).

TABLE 5.10 Summary of completion criteria self-certification monitoring

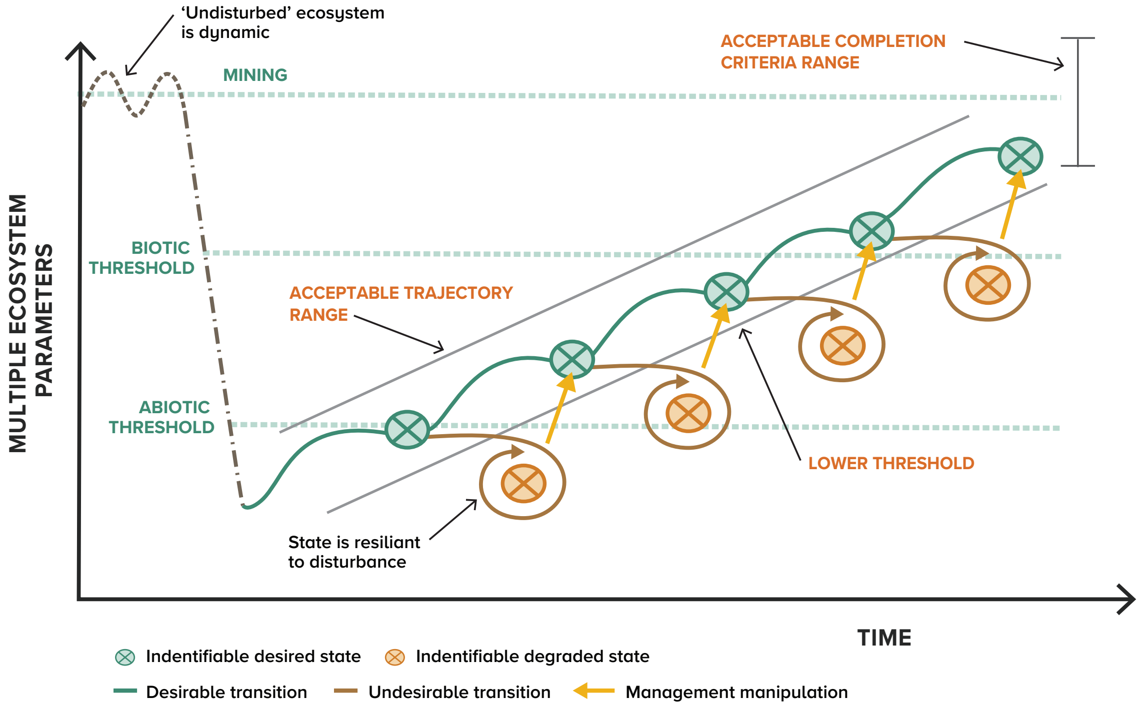
Domain	Rehabilitation action
July — End of first rehabilitation season	• Landscaping: earthworks, pit slopes, burring rocks, pit water holding capacity, access tracks • Soil Return and Fauna: Topsoil cover, fauna habitat, pit level • Contour Ripping • Seeding
March/April — 9 months after rehabilitation initiated	• Plant Density: legumes, jarrah, marri. • Weeds • Erosion • Bare areas
October/November — 15 months after rehabilitation initiated	• Species richness

Source: Adapted from Alcoa (2015)

Thirdly, in the second year after establishment at 15 months of age, monitoring is conducted to measure plant species richness. Results from monitoring plots in rehabilitation are compared with similar plots in the reference unmined forest to obtain a percentage species richness return. Alcoa set a target of 100% species richness return in 1996, which was first achieved in 2001 (Koch 2007b).

A subset of plots assessed for species richness in the second year are retained as permanent plots. These are re-monitored at increasing intervals to assess longer-term ecosystem development, providing confidence that the regenerating forest is tracking on a satisfactory trajectory and able to meet the requirements of various future forest uses. Long-term plot data are also useful inputs for research studies investigating various aspects of ecosystem development and function (e.g. Grant 2003; Grant 2006; Grant & Koch 2007; Source: Grant (2006, p. 30) Figure 5.14).

In addition to flora monitoring, a long-term program monitoring fauna return and use of rehabilitated areas is conducted on a periodic basis. Designed in 1991, the program surveys the return of mammals, birds, reptiles, frogs and ants in healthy upland forests, in stream zone vegetation and in rehabilitated areas of increasing age (Nichols & Nichols 2003). The program provides information on patterns of recolonisation, identifies species that are slow to recolonise rehabilitated areas (which may become subjects for further research) and monitors fauna population dynamics in the surrounding unmined forest.



Source: Grant (2006, p. 30)

FIGURE 5.14 Key states in the rehabilitation process including transitions that require remedial action

EVALUATION

Alcoa's completion criteria are reviewed on a periodic basis. Such reviews consider the latest research and monitoring results, as well as advances in technology, including cost-effective rehabilitation techniques (Nichols *et al.* 2005). In this way, Alcoa is able to both meet current regulatory standards, and anticipate and influence higher standards across the broader industry (Grant & Koch 2007). Two revisions of completion criteria for jarrah-dominant rehabilitation have been completed to date. The format and examples of completion criteria for current rehabilitation are given in Table 5.11.

For example, early research showed the importance of fresh topsoil for rehabilitation of diverse jarrah forest (Tacey & Glossop 1980) which has influenced practice thereafter. More recently, research on P-fertiliser effects on vegetation development has resulted in Alcoa reducing rates of P-fertiliser application from 80 to 40kg per ha (e.g. Daws *et al.* 2015). Where relevant, revision is conducted by mutual agreement between Alcoa and the regulatory authority. In the case of reduced P-fertiliser, DBCA has requested more research into the long-term effects on jarrah forest restoration (e.g. Daws *et al.*, 2019) before ratifying it as standard practice. Efforts to restore not only plant species richness but also similar species composition to reference forest are ongoing and may eventually inform the development of new completion criteria.

Completion criteria are supported by formalised Working Arrangements between Alcoa and the DBCA. The Working Arrangements describe in greater detail how mine operations, including rehabilitation, may be conducted. The intent is to maintain a coordinated approach to the management of mining operations and the protection of biodiversity and water resources (Alcoa 2015). Working Arrangements were first developed in 1979 and are regularly updated in part to maintain consistency with revisions to the completion criteria.

TABLE 5.11 Examples of completion criteria established from 2016 onwards

Stage	Criteria and intent	Guidelines for acceptance	Standard	Corrective action
Planning	**Flora and fauna surveys** Flora surveys and fauna assessments have been completed prior to clearing	Plant species and community management plans have been prepared and endorsed by Parks and Wildlife (DBCA) for State and Federally listed flora species and Threatened Ecological Communities.	Field flora surveys have been completed to agreed standards as set in the Alcoa/Parks and Wildlife Working Arrangements for all areas intended to be cleared for mining or infrastructure.	Undertake survey to agreed standards
Rehabilitation Earthworks	**Landscape design** The mine pit areas are landscaped to be stable and to blend in with the surrounding forest	Landscaping must be completed to ensure effective surface water management. Landscape design will not cause an impediment to access for DBCA Parks and Wildlife's operations or be an ongoing financial or management liability. Self-certification by Alcoa annually and / or inspection by Parks and Wildlife confirm landscape design is acceptable. Landform design that meets the standard will be deemed acceptable unless Parks and Wildlife writes to Alcoa within three months of self-certification to advise otherwise.	Slopes must always be less than 18 degrees. No landscaped pit is to have a slope greater than 15 degrees for more than 20 metres unless it is on contour of the surrounding forest floor.	Alcoa to provide documentation and advice to Parks and Wildlife, where self-certification has resulted in non-standard outcomes. Completion criteria checklists will be completed by Alcoa and may be checked by Parks and Wildlife. If Parks and Wildlife finds that any rework is required based on occasional random inspections, then they will state this in writing to Alcoa within 3 months of the completed inspection. Alcoa will undertake remedial works to ensure areas meet the landscape design standard.
Early Establishment	**Establishment of understorey** There is an adequate legume density early in regeneration.	Alcoa must submit 9-month monitoring data to DBCA Parks and Wildlife annually. Parks and Wildlife must review and advise Alcoa of acceptance or request corrective actions. Vegetation establishment monitoring to occur as defined in the Alcoa/Parks and Wildlife Working Arrangements.	Minimum legumes 0.5 per square metre averaged over a pit assessed at 9-months. Monitoring as defined in the Alcoa/Parks and Wildlife Working Arrangements.	Rehabilitated areas that do not meet the standard will be inspected by Parks and Wildlife and planted or seeded if required and re-monitored.
Vegetation 12 years and older	**Management of understorey** There is an adequate understorey layer in the regenerated pit.	Understorey vegetation meets the expected species richness, density and cover.	Evidence from permanent monitoring plots, and research trials that understorey cover density and richness are within the respective ranges observed in forest reference sites.	Rehabilitated areas that do not meet the expectations will be inspected by DBCA Parks and Wildlife and a plan for remedial action will be negotiated with Alcoa and Parks and Wildlife.

Source: Adapted from Alcoa (2015).

5 CHAPTER

Photo courtesy: Alcoa

6 Summary, limitations and recommendations

Extractive industries worldwide face the challenge of supporting an ever-rising demand for raw materials whilst, at the same time, protecting the natural and social environments they operate in. Both regulators and operators must constantly work, learn and adapt to rapidly-changing conditions, fuelled by changes in markets and industry, climate change, growing community needs and expectations, and exponential advances in rehabilitation and monitoring technologies. Across the globe, and in Western Australia, companies have the obligation to rehabilitate their sites to a state that supports post-mining land uses (PMLUs), while avoiding negative environmental and social impacts. This results in the need to define closure objectives and completion criteria that mark the necessary outcomes to be achieved, for the mine to become eligible for relinquishment. Thus, current questions are: 'how should closure objectives and completion criteria be defined and how should progress towards meeting completion criteria be monitored?'.

In response to such need, the purpose of this report and the included framework is to provide a roadmap for the definition of mine completion criteria with associated monitoring that are S.M.A.R.T. — Specific, Measurable, Achievable, Realistic and Time-bound, and will make mines safe, stable, non-polluting and capable of sustaining an agreed PMLU, as required by the Government of Western Australia (DMP 2016). While this project was undertaken within the mine regulatory framework of Western Australia, the processes described can potentially be applied to other Australian and international jurisdictions, as well as to other industries that require similar rehabilitation of disturbed lands (e.g. infrastructure of oil and gas).

The framework described in Chapter 2 provides guidance on how to set *Specific* completion criteria by tailoring them to address definitive attributes of the pre-agreed PMLU. Criteria should be *Measurable*, as they must be defined upon attributes that can be monitored, using a suite of techniques described in this guide. The evaluation of monitoring data against chosen reference sites will inform mining proponents and regulators whether rehabilitation is trending towards the agreed outcomes. Closure outcomes will necessarily be informed by science based evidence, which means that only *Achievable* targets are selected in the definition of completion criteria. Importantly, such targets must be regularly revisited to understand whether they remain achievable as the life of mine and rehabilitation practices progress. The iterative nature of this process ensures that completion criteria remain *Realistic* to the circumstances of the mine site, even as these change and new risks are identified. This approach also results in criteria, monitoring and corrective actions being *Time-Bound*, where possible, along a rehabilitation trajectory whose ultimate goals are for the mine to be closed and relinquished.

This project could not have been completed without the valuable contribution of experts, mining proponents and regulators, who advised about the gaps and opportunities present in relation to mine completion criteria in Western Australia. First, the review of science, guidelines and practices relevant to completion criteria and monitoring helped map the regulatory framework in Western Australia, as well as provide a wider overview across Australia and internationally. This review is the first of its kind, resulting in a comprehensive summary of the available guidelines for the definition of completion criteria and risk-based monitoring methods. The review identifies a broad list of attributes that can be potentially used in the definition of completion criteria, as well as a sub-selection of those that are most recommended and commonly used for projects with PMLUs relating to the natural environment. In addition, the review describes several techniques to monitor and evaluate ecological attributes, and provides guidance on the most appropriate approach, based on the type and level of criticality of each attribute.

Second, personal interviews and a survey involving mining proponents, regulators and consultants provided an understanding of the key challenges faced by closure professionals in Western Australia. Interestingly, while opinions could be expected to vary across stakeholders, analysis revealed shared areas of concern among different stakeholder groups, thus reinforcing the need and opportunity to work collaboratively towards common ground. In response to stakeholder consultation, critical issues that were closely related to definition of completion criteria were added to the scope of this project. The summary provided in Table 6.1 illustrates how identified issues have been addressed in the framework.

TABLE 6.1 Identified gaps and their responses in the framework

	Gaps identified through interviews and survey	How gaps are addressed by the Framework
Post-mining land use(s) (PMLU)	Limited consideration of alternative PMLUs	List of possible PMLUs following the Australian Land Use and Management classification
	Lack of guidelines on selection of PMLUs	Summary of available processes for selection of PMLUs
	Contradiction of preferred PMLUs between regulators and stakeholders	Indication of participatory and objective processes for selection of PMLUs
		Assertion that PMLUs are shaped by existing tenure and must be agreed at an early stage of completion criteria development
Reference(s)	Reference site conditions unrealistic for hard-rock mining	List of possible references and/or benchmarks to ensure selection is appropriate for the site
	Unrealistic benchmarking against reference sites 'what was there before'	Recognition that 'References' can range from baseline conditions to conceptual models, as appropriate to PMLU and agreed through the framework
Completion criteria	Narrow focus on numerical targets and ecological aspects, thus missing 'big picture'	Consideration of holistic approach and assessment of completion criteria as a package of targets
	Contradiction between excessive prescription vs lack of guidance	Framework to be used as a toolkit and tailored to specific needs
	Completion criteria to be risk based	Risk-based attribute prioritisation
	Inconsistent terminology	Glossary provided
Monitoring	Untargeted monitoring without matching against completion criteria	Inclusion of monitoring techniques for attributes in the framework and explicit need to associate with SMART completion criteria
	Lack of monitoring guidelines	Risk-based attribute prioritisation included with risk-based monitoring suggestions

6.1 Policy and knowledge gaps

Several important issues raised throughout the project highlight areas for future work and research directions in the field of mine closure and relinquishment.

6.1.1 Alternative PMLUs

The identification and agreement of PMLUs that differ from land uses that are similar to previous or surrounding land uses (i.e. other than pastoral, conservation or agricultural use) remains an area of complexity. Although the framework presented in this document includes the ability to identify and agree to alternate PMLUs, this process has few precedents in Western Australia.

More broadly, important questions remain on how current practices for the definition and evaluation of completion criteria may be applicable for unconventional PMLUs, such as residential development or renewable energy generation. Indeed, most mine closure plans in Western Australia propose a return to pre-mining conditions, although a gradual change in attitudes was reported by both regulators and mining proponents. Although the harsh climate and remoteness of many Western Australian mines limits the feasibility of certain PMLUs, future research may benefit from learning how other jurisdictions, such as the USA or Europe, accommodate a variety of PMLUs, many of which result in long-lasting, positive outcomes for local communities and beyond.

6.1.2 Setting references and completion criteria standards

The framework steps of setting references and completion criteria standards are also subject to agreement with stakeholders. To date, practice in Western Australia has varied to some extent with different approvals processes, regions and dates, as well as with different PMLUs and impacted values. It will continue to be an area where agreement ultimately requires meeting regulatory expectations. However, further documentation and research into the benefits or costs of particular standards may help to clarify decision processes and trade-offs and avoid application of conservative precautionary principles.

Decades of research and recent technological innovation have led to remarkable improvements in the definition, monitoring and evaluation of mine rehabilitation success, particularly regarding ecological aspects, such as water, soil, vegetation and fauna. However, significant work still needs to be done to advance our understanding of restoration ecology, ecosystem development and contribution to local or regional biodiversity outcomes. Notably, further guidance is needed in Western Australia for the selection of targets for ecological criteria and the interpretation of their value.

6.1.3 Criteria for non-biophysical attributes

In Western Australia, as in other parts of Australia and the world, mine rehabilitation has been largely dominated by a focus on ecological restoration. Conversely, guidance and research on non-ecological aspects (e.g. landforms) stills lags behind. This was confirmed as a major gap through our stakeholder consultation. To make up for current shortcomings, a formal review of non-environmental aspects, attributes and monitoring is recommended as a future project to support revised versions of this report.

6.1.4 Relinquishment

A recurring concern by mining operators relates to the development of clear and transparent relinquishment processes. Mines successfully transitioning through a closure process and achieving relinquishment is a key issue for the resource sector in Western Australia and across Australia. A recent study conducted by The Australia Institute (Campbell *et al.* 2017), and republished by the Parliament of Australia (APH 2017), notes that over 60,000 abandoned mine features exist all over the country whilst less than 25 are known to have been relinquished (LPSDP 2016d). Whilst initial steps have been taken by regulators in Western Australia to improve the transparency of the mine relinquishment process, more work is needed. Currently, there is no documented process for mine relinquishment in Western Australia, even where sites have met agreed completion criteria and been undertaking monitoring for some time. This reflects the complexity of mine closure and relinquishment as a process distinct from mine site rehabilitation. The solution to this issue requires focussed policy consideration, together with transdisciplinary research and activity that develops and integrates knowledge and processes across multiple domains, from engineering and geotechnical disciplines, the ecological and social sciences and economic and finance systems. This needs to be driven by active collaboration between research, policy, mining and METS sector and by policies and guidelines that enable relinquishment and a successful transition to the next land use.

6.1.5 Risk and residual liability

Importantly, one of the main roadblocks for relinquishment is the question of risk and residual liability. Residual liability is a particular challenge to completion and relinquishment, with subsequent land or lease owners unwilling to take on significant remaining liability.

Despite being fundamental to the planning and management of mine operations and closure, the evaluation of risk (levels, likelihood, and consequences) remains contentious — without a consistent set of definitions. The International Standardisation Organisation (ISO 2018) does not provide risk definitions, but rather a series of examples and guiding principles, grounded on the notion that risk is circumstance-specific and, therefore, needs to be defined case-by-case. This 'tailoring' approach leads to undesirable consequences, chiefly, high levels of subjectivity and lack of transparency. Within the context of mine closure and relinquishment, significant knowledge gaps exist, expectations are often high and there is a significant level of uncertainty across a number of areas. This can often lead to poor prioritisation processes that omit critical requirements for successful mine closure or establish unachievable goals that lead to system failure and orphaned mines. Ideally, a unique set of guiding principles for the definition and understanding of risk within the specific context of mine closure would benefit all stakeholders, including companies as well as regulators.

6.1.6 Emerging technologies

Another key area for future policy development in Western Australia is enabling mine closure monitoring to take advantage of future technologies. As frequently occurs in tech-driven industries, advances in tools and methods happen at a much faster pace than regulations can be re-examined and rewritten. Recent monitoring techniques, such as remote sensing, are revolutionising how rehabilitation success is assessed and, thus, which indicators could be used in the definition of completion criteria. Under this optic, it is difficult, if not impossible, to envisage which tools will be commonplace in 10, 20 or 30-years' time — when mines that are now developing their first closure plans are likely to reach their time of closure. When followed diligently, strict regulations have the advantage of helping reduce risk and yet, by the same token, they preclude innovation adoption. Ensuring there is an active link between science and policy development will create robust guidance material while supporting innovation that improves assessment and reporting outcomes.

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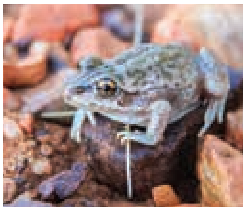


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