

DEVELOPING ECOLOGICAL COMPLETION CRITERIA TO MEASURE THE SUCCESS OF FOREST AND WOODLAND ESTABLISHMENT ON REHABILITATED MINES IN AUSTRALIA¹

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Abstract. Over the last 20 years, mining companies throughout Australia have increasingly adopted an objective of establishing sustainable native ecosystems following mining. A significant area of risk associated with mine closure is the question of completion criteria for native ecosystem rehabilitation – what standards will regulators and the community accept as part of an overall mine closure plan, which if met, will result in lease relinquishment? Two examples from mines located in forest and woodland habitat in different parts of Australia illustrate how companies have adopted an innovative approach to the development of ecological completion criteria.

Alcoa World Alumina Australia mines bauxite in the jarrah forest of south-western Australia. Shallow mining (~4 m) occurs in isolated pods averaging 10 ha in size. The overall objective of rehabilitation is ‘to restore a self-sustaining jarrah forest ecosystem, planned to enhance or maintain water, timber, recreation and conservation values’. Completion criteria were developed after extensive liaison with stakeholders. The criteria are assessed at five different stages, ranging from planning (prior to mining) to late (10-15 years). More than 25 years of research data enabled Alcoa to set criteria that include a range of biodiversity and ecosystem function measures.

Wesfarmers Curragh Mine in central Queensland is located in a woodland environment. The open-cut coal mine produces large spoil areas that are reshaped and planted to an open woodland/grassland community. A recent study recommended completion criteria which state (in part) that ‘The objective of rehabilitation following mining at Curragh is to establish a stable, self-sustaining native ecosystem that fulfils designated land uses including protection of water resources and nature conservation, and which...is similar in composition and function to that occurring in representative unmined reference sites’. Compared to those of Alcoa, the Curragh criteria reflect differences in the pre-mining environment, climate, and the mining operation.

This paper describes the similar approach used to develop completion criteria at the two mines, and illustrates how the issue is being addressed in Australia.

Additional Key Words: succession, reference site, rehabilitation monitoring.

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Introduction

A significant area of risk associated with mine closure is the matter of subjectivity in relation to developing and meeting completion criteria – will the regulators and the broader community accept defined standards as part of an overall mine closure plan, and agree to lease relinquishment? Over the last 20 years, companies throughout Australia have increasingly adopted an objective of establishing a sustainable native ecosystem following mining. It has recently become apparent that a major issue associated with the mine closure process is the question of completion criteria for this native ecosystem rehabilitation – what standards will regulators and the broader community accept as part of an overall mine closure plan, which if met, will result in lease relinquishment?

Both regulatory authorities and mining companies are now addressing this issue across Australia, but there are relatively few examples of mine closure strategies that have been through a full public review process and then been signed off by both the mining company and all regulatory authorities.

Recent examples from Australian mining projects conducted in forest and woodland habitat illustrate how two mining companies operating in very different situations with respect to legislative requirements, climate and vegetation communities, have adopted an innovative approach to the development of ecological completion criteria. This paper describes the systems developed by Alcoa World Alumina Australia, a bauxite mining company with operations in the jarrah forest of south-western Australia, and Wesfarmers Curragh Mine, a large coal mine located in central Queensland. The similar approach developed in these two very different cases illustrates principles that could be adapted to a wide range of situations where the goal is to establish a sustainable native ecosystem following mining.

Case Study 1: Alcoa World Alumina Australia

Alcoa's mining and rehabilitation operations.

Alcoa World Alumina Australia mines bauxite in the south-west of Western Australia, in an area where winter rainfall is predictable and totals around 1200 mm per annum. Mining operations occur within the jarrah forest, which is a tall, dry sclerophyll forest with the overstorey dominated by jarrah (*Eucalyptus marginata* Sm.) and marri (*Corymbia calophylla* (Lindl.) K.D.Hill & L.A.S.Johnson). There is a relatively open midstory of species such as bull banksia (*Banksia grandis* Willd.) and snottygobblers (*Persoonia longifolia* R. Br., *P. elliptica* R. Br.), while the understorey is usually less than 1m high and features a high diversity of shrub and herb species from a variety of families, including the Liliaceae, Fabaceae, Epacridaceae, Dilleniaceae, Restionaceae and Cyperaceae (Bell and Hedde 1989). Although much of the main forest area is uncleared, it has been subjected to disturbances including logging, construction of dams and the impact of Phytophthora Dieback disease, which kills jarrah trees and many understorey plant species. The primary land use in the forest is water catchment, with compatible secondary land uses including conservation, timber production and tourism.

Alcoa's mining operations commenced in 1963. Currently, approximately 550 ha are mined and rehabilitated annually. The ore occurs in 'pods', which usually range from 2-60 ha, with an average of 10 ha. Open-cut mining operations commence with the clearing of vegetation and the stripping of seed and nutrient-bearing topsoil to a depth of 150 mm (Fig. 1). Where practicable,

this is returned fresh to areas being rehabilitated (Fig. 2). Overburden, which varies from 0-1 m, is removed and stockpiled. Bauxite is then mined to an average depth of 4 m.



Figure 1: Topsoil stripping operations



Figure 2: Respread topsoil

After mining, the pit is recontoured to conform with the natural landforms and the pit floor is ripped to remove compaction. Overburden and topsoil are replaced and the final surface is contour ripped to prevent erosion. Local trees and more than 70 understorey species are established by seeding and planting, and fertilizer is applied. Rehabilitation procedures are described in more detail elsewhere (see Ward et al. 1993; Ward et al. 1996; Gardner 2001). A typical rehabilitated site at different ages is shown in Fig. 3 and 4.

The overall objective of rehabilitation is ‘to restore a stable, self-regenerating jarrah forest ecosystem, planned to enhance or maintain water, timber, recreation, conservation and other nominated forest values’. The specific conservation goal is to ‘encourage the development of floral, faunal and soil characteristics similar to those of the indigenous jarrah forest ecosystem’ (Nichols et al. 1991).

To achieve these objectives and ensure continuous improvement in rehabilitation standards, Alcoa has conducted an intensive rehabilitation research program investigating aspects relevant to the re-establishment of floral and faunal communities in the developing forest ecosystem.



Figure 3: Two year-old rehabilitated bauxite mine



Figure 4: The same site 13 years after rehabilitation

Relevant rehabilitation research

Alcoa's research program has enabled the company to measure its progress towards achieving the above objectives, as well as set specific completion criteria and determine whether these have been met, as part of the overall mine closure and lease relinquishment process. Key research areas have included the re-establishment of biodiversity, successional processes, nutrient cycling, sustainability, and resilience to disturbance. Relevant aspects of the rehabilitation program are summarised below:

- Considerable research effort has focused on continuous improvement of the rehabilitation techniques used to establish a jarrah forest ecosystem. This is summarised in Nichols (2003). Key research areas have related to ripping, topsoil handling, fertilizing and seeding. Any cost-effective improvements developed are incorporated into rehabilitation prescriptions.
- Successional studies have investigated the development of floral and faunal communities over time (e.g. Ward et al. 1990, Grant 2003, Nichols 1998, 2003, Nichols and Nichols 2003, Grant 2005). These found that the initial plant species established dominate the vegetation community of a site for a very long time. This is termed the 'initial floristics' model (Egler 1954). It led Alcoa to realise the importance of establishing a diversity of species at the start, and resulted in more effort being put into the research on topsoil handling and seeding methods described above. Detailed fauna studies have focused on groups that indicate key aspects of biodiversity and ecosystem function such as birds (vegetation structure, floristics and insect abundance), reptiles (presence of ground shelter and invertebrates), spiders (vegetation structure and suitable prey), ants (pollination, soil aeration), collembola, mites and termites (nutrient cycling).
- Detailed nutrient cycling research has been carried out to determine whether the nutrient bank is sufficient for a mature forest to develop, and, if so, whether the nutrients will be available to plants when required. Specific projects have related to studies on tree growth, biomass, litter breakdown, leaf tissue analysis, soil microbiology and development of the soil profile (summarised in Nichols 1998, 2003) More recent studies have examined the impact of prescribed burning on nutrient pools in rehabilitated areas (Morley et al. 2003)
- There is no simple measure of sustainability. Recognising this, Alcoa's approach to demonstrating sustainability of the developed ecosystem has focused on interpreting and understanding the findings of the successional and nutrient cycling studies described above. The system is considered likely to be sustainable if it matches the unmined forest in key aspects, and/or no problems are apparent. Thus, rehabilitation that matches the unmined forest in plant species richness and ecological function, and supports comparable populations of key faunal groups, is considered likely to be sustainable.
- Resilience of the rehabilitated forest ecosystem to fire has been studied in detail. Fire is a recurring element of the jarrah forest ecosystem, and it is essential that the rehabilitated mines can be managed in conjunction with the surrounding forest using managed burning prescriptions. Vegetation studies have monitored the post-burning response of a range of parameters including fuel load, tree growth, plant density, live plant cover, species richness, weed response, Acacia density and cover (Grant et al. 1997; Grant et al. 1998; Smith et al. 2000; Grant 2003; Smith et al. 2003). Detailed fauna studies have also been conducted to assess the response of vertebrate (Nichols and Nichols 2003) and invertebrate (Brennan

2002) fauna. As a general rule, these studies show good recovery of key components of the rehabilitated forest ecosystem following fire.

Development of Alcoa's completion criteria

Alcoa's completion criteria were developed in response to a Government Ministerial condition (MPR 2004; much of the following is summarised from this document). The condition required:

- Public consultation prior to finalisation of the completion criteria;
- Review and revision of the completion criteria every five years;
- Application of best practice environmental management principles; and
- A certificate of acceptance granted by the Western Australian Department of Conservation and Land Management (CALM) prior to relinquishment.

The process and the resulting criteria had to meet the requirements of the Mining Management Program Liaison Group (MMPLG), an interdepartmental State government committee established to review and approve Alcoa's mine plans. The developmental process involved public meetings, site inspections, and a public review period during which submissions could be made to the Minister for Environment and the Western Australian Environmental Protection Authority.

Two separate sets of criteria were developed. Completion Criteria for Current Era Rehabilitation (post-1988), approved in 1998, cover all areas rehabilitated using methods similar to those currently used. Completion Criteria for Early Era (pre-1988) Rehabilitation, approved in 2002, cover all areas rehabilitated using more outdated methods. The distinction recognises that different standards applied at the time, and techniques were not as refined, so it is not reasonable to expect the same outcomes as in post-1988 rehabilitation.

The Completion Criteria for Current Era Rehabilitation were developed by a joint Alcoa/CALM working group. They were based on a set of principles that were considered appropriate for mine rehabilitation in the northern jarrah forest. These include:

- Meets land use objectives;
- Is integrated into the landscape;
- Exhibits sustained growth and development;
- Vegetation is as resilient as jarrah forest; and
- Can be integrated with forest management.

Selected examples of Completion Criteria for Current Era Rehabilitation are given in Appendix 1. Essentially these represent a staged process, where rehabilitation is assessed against completion criteria at the following stages: planning (prior to mining), very early (rehabilitation phase), early (0-5 years), mid (5-10 years) and late (10-15 years). Table 1 shows the matrix of principles assessed over the various time categories.

Table 1: Matrix of principles versus stages of assessment of Alcoa’s completion criteria.

Stage	Principles				
	Land Use	Integrated Landscape	Sustainable growth and management	Resilience	Integrated management
Planning	Yes	Yes	Yes		Yes
Very early	Yes	Yes	Yes		Yes
Early		Yes	Yes	Yes	Yes
Mid				Yes	
Late	Yes	Yes	Yes	Yes	Yes

The steps required to receive a certificate of completion include:

- Self-certification by Alcoa at the various stages described above. This must be supported by monitoring data and self-audit checklists, to confirm that each task has been carried out to the required standard.
- Monitoring data and rehabilitation checklists are provided annually to CALM or on request, to allow audits.
- Final assessment and site inspection is carried out by CALM and other land management agencies to confirm that self-certification is complete and standards have been met.
- The MMPLG reviews self-certification and land management agencies’ recommendations, and authorises CALM to issue a certificate of completion.
- CALM issues a certificate of completion on behalf of the State government.

The completion criteria are based on the standards that should be achieved if Alcoa applies current best practice as prescribed in Working Arrangements. These are a set of prescriptions for how operations, including rehabilitation, should be conducted. They are regularly reviewed and updated as new research findings become available. Long-term monitoring and research programs give confidence that, if the standards are met, rehabilitation will be sustainable and will meet land use objectives in the long-term provided normal forest management procedures are implemented.

The Completion Criteria for Early Era Rehabilitation were developed using a similar approach and are based on the same principles as those for Current Era Rehabilitation; however, there are some differences in the method of applying them.

It is recognised that rehabilitation carried out prior to 1988 will require varying degrees of rework. The Working Arrangements were developed in 1979, so rehabilitation after that time should have been carried out according to these requirements and should therefore require less reworking. In all cases, the extent of reworking is determined using Rehabilitation Assessment

Sheets. A scoring system is used to determine whether corrective action may be necessary, and if so, the extent of reworking required. Re-working prescriptions aim to increase numbers of native jarrah forest species and disfavour non-indigenous species (such as eastern Australian eucalypts). Other reworking can include removal of pit faces and large contour banks, and installation of access tracks for fire management. The extent of reworking varies according to age, with more than 70% of the oldest rehabilitation (1966-1970) at the Jarrahdale mine having been re-rehabilitated because it did not meet the completion criteria.

Both Current and Early Era Completion Criteria have been extensively evaluated in the field, and, as noted earlier, there is a requirement that they be reviewed at five-yearly intervals.

Progress towards achieving mine closure and relinquishment

To date, no large areas of Alcoa's rehabilitation have been relinquished. This has largely been due to Alcoa focusing research on long term management issues of rehabilitation to demonstrate sustainability and the lack of availability of large sub-regions of rehabilitated areas of sufficient size to justify instigating the completion criteria process. However, two large mining sub-regions are now available to be assessed against the completion criteria. Alcoa intends to put in a submission to the MMPLG for full assessment of these areas in the next few years.

In a recent review of progress of Alcoa's rehabilitation against the principles of the completion criteria identified above, the major concerns that were raised related to resilience and integrated management, particularly in relation to fire. The major issues of relevance to the completion criteria that have been raised are:

- Research and monitoring relating to burning of rehabilitation areas;
- Most appropriate fire regime for rehabilitated areas;
- Fire risk assessments and planning;
- Stocking of rehabilitation with fire resilient overstorey species; and
- Integration of silvicultural and burning practices.

A number of research projects relating to fire management have been undertaken in rehabilitated areas over the last 15 years (Grant 2003). A total of 783 hectares of pre-1988 (477 ha) and post-1988 (306 ha) rehabilitation has now been burnt in various seasons, with the majority of area being burnt in spring (590 ha). Alcoa is now working closely with CALM, the government agency responsible for undertaking prescribed burns, and the MMPLG to more clearly define where further research or monitoring in relation to fire management of rehabilitated areas may be required.

The first review of the post-1988 completion criteria has been undertaken and is nearing completion. The additional research and monitoring data that has been collected since the criteria were initially established has been invaluable in updating the criteria and making many of them more quantitative rather than qualitative. As part of this review, a more detailed stepwise handback process has been developed that more clearly outlines the required data and paperwork to get sign-off. At the time of writing this paper, this process had not been signed-off by the MMPLG and was therefore not available to include in this document.

Case Study 2: Wesfarmers Curragh Mine

Curragh's mining and rehabilitation operations

Curragh is an open-cut coal mine located in central Queensland's Bowen Basin coal mining region. Rainfall is low (around 600 mm) and much less predictable than that experienced at Alcoa's operations. The principal vegetation types represented in the area around Curragh include tall Brigalow (*Acacia harpophylla* F. Muell. ex Benth.) scrub, Poplar Box (*Eucalyptus populnea* F. Muell.) open woodland, and remnant eucalypt woodland vegetation along Blackwater Creek. No rare plants have been recorded in botanical surveys; however, an Endangered Regional Ecosystem exists on private property immediately south of the mine lease.

Prior to mining, the lease area was used primarily for beef cattle raising with some grain production. These activities resulted in almost 80% of the land area being cleared, with remaining uncleared areas also grazed. After mining commenced, grazing was excluded from much of the existing lease, resulting in extensive areas of Brigalow scrub regrowth and some woodland regrowth.

Mining commenced in 1982 and the mine currently produces approximately 5.8 million tonnes of product coal per annum (Curragh 2002). In the process, 75 million tonnes of overburden are moved and placed in spoil piles that are reshaped and rehabilitated. Up to June 2002, a total of 3064 ha had been cleared for mining and related operations. At that time, 1163 ha was available for rehabilitation, with 69% of this recontoured and topsoiled, and 63% seeded.

Mining operations are similar to those used at many other coal mines in the Bowen Basin. Prior to mining, topsoil is removed and respread on reclamation areas or stockpiled. After drilling and blasting, electric walking draglines are used to remove the overburden spoil material (Fig. 5). The exposed coal seam is ripped by dozer, loaded into haul trucks and taken to the coal handling and preparation plant.

Spoil is reshaped using bulldozers. Due to the swell factor, the final landform is higher than that of the surrounding land. The overall impression of the rehabilitation is that of a rolling landscape with occasional water-gaining areas becoming established with wetland plants.

After spoil is reshaped, erosion control structures are installed. Topsoil is then replaced in strips, which are approximately 10-15 m wide, 20 cm deep, and at a gradient of 0.5% off contour. The strips are separated by bare spoil because early research (Mulligan and Bell 1991) showed that dense growth of the introduced pasture Buffel grass (*Cenchrus ciliaris* L.) from seed stored in topsoil prevented the successful establishment of native plant species. On outer boxcut slopes, proportionally less bare spoil is left because of the need to establish rapid grass cover for erosion protection. Deep ripping and seeding are carried out simultaneously, using seed boxes mounted on the dozer. A native tree and shrub mix is applied to bare spoil, whilst a grass/legume mix is applied to topsoil strips (Fig. 6).

Extensive research and monitoring has been carried out at Curragh. This is seen as part of a continual improvement process, with the purpose of understanding key aspects of the rehabilitated ecosystem, improving rehabilitation techniques, and determining whether the resulting vegetation and faunal communities will be sustainable and fulfil their designated functions over the long-term. Previous and ongoing research project areas have focussed on tree and understorey establishment, soil nutrients and soil microbiology, native ecosystem development, and flora and fauna success criteria.

As well as helping refine rehabilitation techniques, the considerable amount of research conducted at Curragh has given an indication of how rehabilitation performs, or is likely to perform, over the long-term. This research has proved very useful in the development of completion criteria.



Figure 5: Removing overburden and constructing spoil piles



Figure 6: Rehabilitation showing tree and grass strips

Background to the development of completion criteria at Curragh

The Curragh completion criteria were developed as part of a project funded by the Australian Coal Association Research Program (ACARP). The objective of this project was to develop an agreed, workable process, for addressing relevant issues relating to mine closure and associated completion criteria when establishing native vegetation communities following coal mining in Queensland's Bowen Basin. The project was intended to reduce the uncertainty relating to completion criteria for native ecosystem establishment. The full report can be obtained from ACARP (Nichols 2004) and should be consulted as it explains the process used in much greater detail.

The project involved conducting a search of published and unpublished literature to review processes that have worked elsewhere, and visiting 11 coal mines to discuss relevant mine closure issues. As the process evolved, two case studies were used to illustrate how it should work in practice. One of these case studies was Curragh.

The process developed involved integrating a number of key components related to the establishment, monitoring and management of rehabilitation. These are described in detail in Nichols (2004) and consist of:

- Setting attainable objectives based on what can be achieved using good practice rehabilitation, allowing for site and technical limitations, and adopting a whole-of-lease perspective;
- Developing monitoring and research programs that will facilitate continuous improvement in rehabilitation standards, and reveal how the ecosystem is developing. This should include monitoring of unmined reference sites for comparison, the use of indicators to assess key aspects of ecosystem development, and the assessment of long-term sustainability under the proposed management regime;

- The project recommended that a number of general procedures should be followed when developing the specific completion criteria. These are:
 - Where appropriate, the criteria should include both prescriptive criteria (to confirm that certain actions have been carried out) and performance criteria (to confirm that rehabilitation has attained an agreed standard or milestone);
 - Criteria should be divided into stages of the operation, *viz.* planning, establishment, development and signoff, and post-relinquishment monitoring and maintenance;
 - Development of criteria, standards and milestones should, where possible, be an iterative process, with initial general criteria set, cost-effective best practice rehabilitation implemented, the results monitored, and the criteria revised according to what is found to be achievable through monitoring and research (Figure 7);
 - Consultation with all relevant stakeholders is an essential component of the development of agreed completion criteria;
 - When finalised, completion criteria should be thought of as ‘trigger levels’. Failure to meet them should ‘trigger’ an internal investigation into the likely causes. A joint decision on whether to implement remedial action(s) should be made by the company and the relevant regulatory authority; and
 - Completion criteria, standards and milestones should be reviewed regularly (e.g. every 5 years) and, where necessary, revised by mutual agreement between the company and the regulatory authority, to take account of significant advances in cost-effective rehabilitation techniques.
- Post-closure and post-relinquishment monitoring and management requirements need to be clearly determined, and both the responsibility for implementing them, and sources of funding clearly defined.

Development of Curragh’s rehabilitation objectives and completion criteria

The process used to develop completion criteria at Curragh follows that outlined above for other Bowen Basin mines, and is summarised in the following sub-sections. A full description of the process and criteria is given in Nichols (2004).

Recommended rehabilitation objective. A specific rehabilitation objective was developed following discussions with company staff. This is summarised below, and takes into account surrounding land use and conservation values, any site or technical limitations, and post-mining management requirements. It provides specific detail and direction, and forms the basis for developing a rehabilitation monitoring program and completion criteria to determine whether the objective has been met.

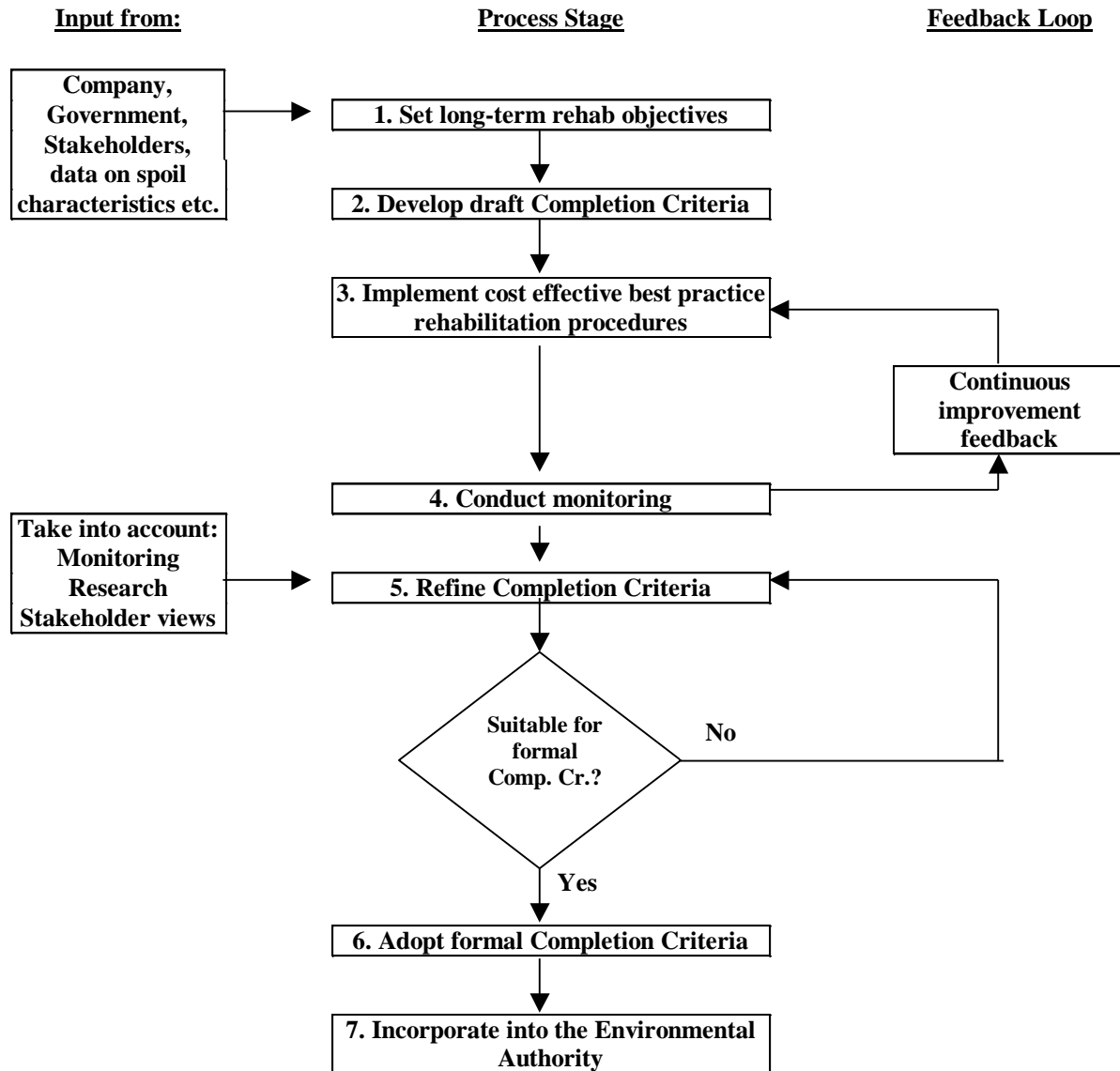


Figure 7: Suggested flowchart used to develop completion criteria. The criteria developed should be reviewed at least every 5 years, and where necessary to take account of advances in cost-effective rehabilitation techniques.

The objective of rehabilitation following mining at Curragh is to establish a stable, self-sustaining native ecosystem that fulfils designated land uses including protection of water resources and nature conservation, and which:

- Represents what can be achieved using cost-effective rehabilitation procedures that reflect mining industry current best practice;

- Is similar in composition and function to that occurring in representative unmined reference sites (including regrowth areas);
- Provides habitat for a range of native vertebrate and invertebrate fauna species;
- Is based on the findings of research into the establishment of ecosystem function, biodiversity and sustainability;
- Is compatible with Curragh's overall whole-of-lease land management approach, which includes protection of remnant vegetation adjacent to Blackwater Creek, and exclusion of grazing from Brigalow regrowth within fenced off sections of the active mining area;
- Takes into account the views of the Curragh Community Consultation Group and other relevant stakeholders;
- Results in either no measurable, or acceptable off-site impacts; and
- Management requirements (e.g. maintenance of access tracks and prescribed fire) are not greater than those of areas prior to mining, or where extra management actions may be required, a mechanism has been put in place for addressing these.

The above objective and associated completion criteria and target standards will be reviewed by Curragh and Queensland Environmental Protection Agency representatives at least once every 5 years, and if necessary, they will be revised by mutual agreement to reflect advances in cost-effective rehabilitation techniques.

Recommended monitoring program. The monitoring program developed, in conjunction with previous and current research projects, is designed to enable Curragh and other stakeholders to assess whether the objectives described above have been met, and the completion criteria listed in the following section have been fulfilled. The monitoring and research also form a key part of Curragh's continuous improvement program. It should be noted that the extensive research on ecosystem development that has already been conducted at Curragh has been taken into account in the design of the monitoring program, which, in several aspects, is less detailed than that which would be required at some other mines, due to the extensive amount of information already available.

The recommended rehabilitation monitoring program consists of two components:

- General rehabilitation assessment monitoring; this is designed to assess the progress of rehabilitated ecosystems and provide information for continuous improvement.
- Rapid assessment prior to signoff is intended to confirm that all completion criteria listed in the following section have been fulfilled prior to closure and relinquishment.

The recommended design for general rehabilitation assessment monitoring consists of transects established across rehabilitated areas to sample the variation in slopes and contour directions. Monitoring plots 50 m x 10 m will be established along these transects with subsequent plots 150 m apart.

In each 50 m x 10 m plot, measurements should include tree and *Acacia* density, tree diameter at breast height, an assessment of tree health, grass cover, understorey species present, presence and abundance of weeds, soil chemical and physical properties, and the extent of erosion. The methods are described in detail in Nichols (2004). Unmined reference sites will

also be monitored using the same techniques, for comparison with the developing rehabilitation. These will be chosen to reflect the variability in vegetation type, location and degree of disturbance present in unmined areas.

This combination of biodiversity, growth and functional measures will enable Curragh to assess long-term ecological trends, and for key parameters, if required, the company will be able to statistically compare any site with itself over time, or with other rehabilitated and reference sites. Maintenance of good records on rehabilitation techniques used is essential for the interpretation of monitoring results and continuous improvement of rehabilitation procedures.

When it is thought that a rehabilitated unit is ready for signoff, the following Rapid Assessment Procedure will be undertaken:

- Collation of all relevant records, monitoring and research data for the area, to determine whether all completion criteria standards and milestones have been met;
- If the site has been monitored, much of the information required will be available from this, together with rehabilitation records, checklists and research findings;
- If the site has not been monitored, a rapid belt transect procedure (Nichols 2004) should be used to determine whether all measurable standards and milestones have been met;
- A general inspection will be conducted to confirm that rehabilitation operations have been carried out as required (or as best as can be determined, for older sites).
- During long-term monitoring or rapid assessment, a site worksheet should be prepared, which summarises key rehabilitation operations, describes the rehabilitation in general terms, and notes any remedial actions that may be required to meet particular standards and milestones (e.g. repair of waterways or erosion gullies, establishment of trees where initial establishment was poor).
- When all records have been collated and any required remedial work completed, a site inspection with the responsible EPA officer should be conducted to confirm their agreement that requirements have been fulfilled, or if not, determine what further work is needed.

Development of completion criteria. Selected completion criteria developed for Curragh are shown in Appendix 2. It should be emphasised that these only apply to the establishment of native ecosystems and related rehabilitation aspects, and therefore only constitute part of the overall mine closure plan. The table takes into account all identified indicator categories and is based on a staged approach, which requires that Curragh meet defined standards or milestones at the following stages:

1. Planning – this requires that all objectives, procedures, landform plans, monitoring and research programs have been developed to the satisfaction of regulatory authorities.
2. Establishment – this requires that all rehabilitation has been carried out according to agreed procedures, and appropriate records kept.
3. Development and sign-off stage – this sets required standards and milestones for the developing rehabilitated ecosystem, focusing on key aspects and indicators relating to vegetation, fauna, landform stability, soils and land use.

4. Monitoring and maintenance – this addresses post-closure and post-relinquishment issues relating to monitoring, management, ownership and liability, funding and risk assessment.

The type of criteria listed vary in detail. Some require that certain actions be carried out, such as ripping and topsoil spreading, and auditable records be retained to verify they have been done. Others may require detailed research and monitoring on specific areas, such as those demonstrating that nutrient cycling processes are proceeding satisfactorily, or total soil erosion rates do not exceed a stated rate. Some criteria are designed to be verified by the monitoring program described in the previous section. And finally, some criteria require that mechanisms be in place for addressing relevant post-closure and post-relinquishment issues, thereby ensuring that, once all criteria have been met, Curragh will have no ongoing liability in relation to rehabilitation establishment.

Summary – key aspects relevant to developing ecological completion criteria

Although the two case studies discussed represent very different situations, they both illustrate a number of key aspects that should be taken into account by any mining operation when developing completion criteria for sustainable native ecosystem rehabilitation. These include:

- The setting of overall objectives and completion criteria should be a consultative process involving the mining company, regulatory authorities, local community and any other relevant stakeholders;
- Overall objectives, as well as specific targets and standards, should only represent what can be achieved using recognised cost-effective good practice rehabilitation;
- The setting of specific targets will often need to be an evolving process: implement good practice rehabilitation, measure key indicators, develop more specific targets based on what is shown to be achievable, and integrate these into the revised closure plan;
- Monitoring and research are critical components of the whole process, in terms of ensuring continuous improvement, developing completion criteria, and determining whether they have been met; and
- The assessment of rehabilitated ecosystem sustainability must be based on sound monitoring data, and must apply to the specified post-mining land management practices.

Experience at a number of mines in Australia has demonstrated that, if the procedures described in this paper are followed, achievable completion criteria can be developed, resulting in sustainable rehabilitation and a streamlined mine closure process.

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APPENDIX 1: Selected examples of Alcoa’s completion criteria.

Criteria and Intent	Guidelines for Acceptance	Standard	Corrective Action
1. PLANNING			
1.2 Sustainable Growth and Development			
1.2.1 Vegetation establishment			
<p>(a) Has a rehabilitation plan been developed for the area which identifies how the area will be revegetated?</p> <p>(b) Has a soil movement plan been developed for the movement of topsoil?</p>	<p>Rehabilitation plans exist for all rehabilitated areas identifying vegetation to be used, rates of seeding or planting.</p> <p>Soil movement plans exist which cater for the use of topsoil and overburden on the mine.</p>	<p>All vegetation requirements are catered for in the plan.</p> <p>Topsoil is allocated to all areas or alternative strategies are prepared.</p>	<p>A plan may need to be developed.</p> <p>Plan modified to ensure topsoil is used preferentially to maximise sustainable growth.</p>
2. VERY EARLY			
2.1 Sustainable Growth and Development			
2.1.1 Vegetation establishment			
<p>(a) Has the area been deep ripped?</p> <p>(c) Is there an adequate cover of topsoil?</p>	<p>All ripping must prevent water runoff and soil erosion; Riplines must not discharge water into forest; Ripping must be as per criteria established in CALM/Alcoa working arrangements.</p> <p>Topsoil should be spread across the whole rehabilitated area. Areas (less than 0.5 hectares) not receiving topsoil are acceptable provided these areas do not exceed 10% of the rehabilitated area.</p>	<p>No uncontrolled water runoff or soil erosion.</p> <p>Topsoil is spread over a minimum of 90% of the rehabilitated area.</p>	<p>Areas of unacceptable erosion to be re-worked and erosion control methods applied.</p> <p>Topsoil or additional seeding/ fertilizing may be spread over the bare areas.</p>

APPENDIX 1: Selected examples of Alcoa's completion criteria (continued).

Criteria and Intent	Guidelines for Acceptance	Standard	Corrective Action
3. EARLY			
3.1 Sustainable Growth And Development			
<p>3.1.1 Sustainability of overstorey (a) Are there adequate numbers of both jarrah and marri trees?</p> <p>3.1.2 Sustainability of understorey (a) Is there an adequate legume content? (b) Are there any bare areas other than sumps greater than 0.5 of a hectare? (c) Is there an appropriate species richness?</p>	<p>Rehabilitated areas must have a stocking rate which will meet proposed land use.</p> <p>Areas to have at least one legume/m². Areas up to 0.5 of a hectare not meeting the standard are acceptable provided they are not greater than 10% of the pit.</p> <p>As above.</p> <p>Areas to have a representative number of forest species present.</p>	<p>An average of 1300 stems per hectare to be present at 9 months over 65% of the pit, of which at least 200 stems are marri to ensure that dieback does not devastate the site.</p> <p>1 legume/m² based on 9 month establishment monitoring.</p> <p>There are no areas greater than 0.5 of a hectare with less than 1 legume/m².</p> <p>Minimum of 50% of forest controls based on 15 month monitoring.</p>	<p>Rehabilitated areas not meeting the standard will be re-planted as required.</p> <p>Areas will be scarified and seeded with legumes.</p> <p>Areas of 0.5 hectares or greater not stocked at the rate of 1 legume/m² to be reseeded the following autumn.</p> <p>Areas may need to receive additional seed. Sites to be scarified and seeded.</p>
4. MID			
4.1 Resilience of Vegetation			
<p>4.1.2 Fire (a) Are there adequate stocking rates of eucalypts and understorey species capable of regenerating after a wildfire?</p>	<p>Guidelines for acceptance still being established based on fire. checklist.</p>	<p>The site is capable of recovering from a wildfire.</p>	<p>Treatments may be needed such as reseeded or thinning of areas.</p>

APPENDIX 1: Selected examples of Alcoa’s completion criteria (continued).

Criteria and Intent	Guidelines for Acceptance	Standard	Corrective Action
5. LATE			
5.1 Sustainable Growth And Development			
5.1.1 Sustainability of overstorey (a) Are there adequate numbers of both jarrah and marri?	Numbers need to be adequate to meet the designated land use. Tree crowns need to be healthy, of suitable density and in proportion to their tree height.	Minimum of 300 stems per hectare with the potential to produce trees with sawn timber potential.	A thinning may be required
5.2 Land Use			
5.2.1 Recreation (a) Where recreation is a priority have recreation plans been implemented? 5.2.2 Timber production (a) Does the site meet timber production requirements for its age? 5.2.3 Catchment protection (a) Does the site conform to catchment management guidelines	The area needs to meet the requirements of any agreed recreation management plan. Where timber production is a primary land use the site will be evaluated against a timber production checklist. Catchment is protected by ensuring stream water quality standards are met, and there is a stable surface. Vegetation density meets the needs of catchment protection and designated land use.	Recreation plan implemented. Site meets agreed timber production guidelines for its age. Areas will be stable with no evidence of recent erosion which would compromise stream water quality as determined by visual inspection.	Undertake prescribed work as required. Re-establish more eucalypts? Sites with erosion compromising stream water quality or land access will be reworked.

APPENDIX 1: Selected examples of Alcoa’s completion criteria (continued).

Criteria and Intent	Guidelines for Acceptance	Standard	Corrective Action
5. LATE (cont'd)			
5.4 Resilience of Vegetation			
<p>5.4.1 Dieback (a) Is there an adequate stocking of resistant native tree species?</p> <p>5.4.2 Fire (a) Are there adequate stocking rates of eucalypts and understorey species capable of withstanding a burn or wildfire?</p> <p>5.4.3 Insects (a) Is the area being preferentially attacked by insects? If so, is insect damage causing adverse impact on the health of the plant?</p>	<p>A dieback-resistant eucalypt species at an adequate stocking rate needs to be present.</p> <p>Area meets guidelines as per fire checklist.</p> <p>An assessment should be made as to the extent of any insect damage (crown or bole damage) and determine whether the rehabilitation is being selectively attacked in the region? Is a treatment warranted?</p>	<p>100 stems/ha of marri or other resistant species to be present.</p> <p>The site is capable of being burnt in a mosaic pattern.</p> <p>No minimum standard.</p>	<p>Plant resistant species as required.</p> <p>Silvicultural treatment or flattening of understorey may be considered.</p> <p>Carry out corrective action where a treatment is required.</p>
5.5 Integrated Management			
<p>5.5.2 Fire (a) Does the site have the potential to be integrated into broadscale burning?</p> <p>5.5.3 Multiple Land Use (a) Does the site have the potential to meet other land uses such as for honey and wildflower production?</p>	<p>Area meets guidelines as per fire checklist. A fire plan has been developed.</p> <p>Area is capable of meeting alternative land uses.</p>	<p>The site is capable of being burnt in a mosaic pattern.</p> <p>Area meets designated land use as shown on MMPLG agreed 25-year plan overlay.</p>	<p>Silvicultural treatment or flattening of understorey may be considered.</p> <p>Carry out corrective action where a treatment is required.</p>

APPENDIX 2: Selected examples of Curragh completion criteria

Rehabilitation Criteria	Standard or Milestone Required	Suggested Corrective Action
1. Planning Stage		
Rehabilitation objectives	Clear rehabilitation objective have been developed in consultation with EPA and other stakeholders	Develop and agree on objectives
Rehabilitation procedures documented	Agreed rehabilitation procedures have been developed and are described in relevant planning and management documents.	Develop agreed rehabilitation procedures
Monitoring and research	Rehabilitation monitoring and research programs designed to assess conformance with requirements and development of rehabilitation, and enable continuous improvement, have been implemented and will continue, where necessary, during the life of the operation	Design and implement rehabilitation monitoring programs
2. Establishment Stage		
Rehabilitation has been carried out to the standards required in the Environmental Authority	An Initial Post-establishment Monitoring Checklist has been completed as a quality control procedure, to confirm that all required rehabilitation works have been carried out	Any operations not carried out to the required standard will be redone if required (e.g. if significant erosion potential exists)
Has topsoil been returned?	Topsoil has been respread in strips on rehabilitated areas, with increasing proportion of topsoil as slope increases, particularly for outer boxcut spoil. Where available and practical, topsoil likely to contain viable native seed has been respread directly onto rehabilitated areas	Respread topsoil if significant problems with vegetation establishment are apparent (especially on slopes), and monitoring shows lack of topsoil to be the cause
3. Development and Sign-off Stages		
3.1 Vegetation establishment and sustainability		
Tree species composition is compatible with that of other vegetation types in the lease, i.e. it includes:		
- local eucalypt species	A range of local eucalypt species are present, including <i>E. populnea</i> and <i>E. citriodora</i>	Plant or seed more species if required

APPENDIX 2: Selected examples of Curragh completion criteria (continued)

3. Development and Sign-off Stages (continued)		
- local tall acacia species	A range of local acacia species are present	Plant or seed more species if required
Tree health	More than 75% of trees are healthy and growing as indicated by long-term monitoring	Investigate causes of problem and correct if required
Leaf nutrient analysis	Nutrient analyses conducted on trees in representative areas indicate no deficiencies of key macro- or micro-nutrients	Investigate causes of any problems and address as required
Tree density	Monitoring or visual estimation show the density of trees >2m tall to be >100 stems/ha, averaged over the rehabilitated unit	Plant or seed more trees if required
Presence of treeless areas	No treeless areas greater than 1ha are present	Correct using planting or seeding if required
Evidence of tree regeneration	Second generation tree seedlings are present or likely to be, based on monitoring or research in comparable older sites	Conduct follow-up assessment later, or add seed if required
Sufficient grass cover, rocks, logs, etc. are present on outer boxcut slopes and steeper inner slopes to control erosion in the long-term	Monitoring and visual estimation show grass cover to be >50% on these areas, or sites have sufficient rock cover to maintain erosion below target standards (see Criteria 3.3)	Where necessary, delay closure until grass cover increases, or increase cover by seeding
Shrubs	A range of native shrub species are present	Investigate the feasibility of establishing more shrub species and do so if practicable
Noxious weeds	A management program for the control of declared plants has been implemented on the site	Control declared plants as per the management program
Fire tolerance	Tree, understorey and grass species are capable of either surviving or regenerating following a fire	Rehabilitation may be too young to determine this; investigate using research and/or literature review of relevant research on other mines

APPENDIX 2: Selected examples of Curragh completion criteria (continued)

3. Development and Sign-off Stages (continued)		
Drought tolerance	Tree, understorey and grass species are capable of surviving drought, as demonstrated by recent monitoring and research results (following a period of severe drought from 2001-2003)	If large-scale deaths have occurred, consider the need for replanting or reseedling, and whether more drought tolerant species should be included in the seed mix
Sustainability	Monitoring and research results indicate that the rehabilitation is likely to be sustainable over the long-term, if managed according to the procedures defined in Criteria 4 below	If sustainability has not been demonstrated for a site, depending on the circumstances, the response could include corrective actions, or postponing signoff until it has
3.2 Fauna habitat and faunal recolonisation	Fauna habitat in rehabilitated areas matches that in some surrounding unmined areas (e.g. Poplar Box woodland), or will do so in time	Investigate whether further planting or seeding might be required as per Criterion 3.1
Fauna recolonisation – invertebrates	Studies demonstrate that key invertebrate functional groups such as ants and soil faunal communities are re-establishing	Investigate the causes where key groups have not recolonised
Fauna recolonisation – vertebrates	Vertebrate surveys demonstrate that bird, mammal, reptile and frog communities are becoming established in rehabilitated sites	Investigate the causes where key vertebrate groups have not recolonised
Management of fauna habitat in unmined areas	Where possible, fauna habitat of adjacent unmined areas will be protected from clearing and grazing as part of Curragh’s overall lease management program, and because such areas constitute sources of recruitment for both fauna and flora to rehabilitation	Protect areas of adjacent native fauna habitat
3.3 Landform stability		
Absence of significant erosion – gullies	No erosion gullies >2m deep and/or 2m wide are present on the outer boxcut slopes	Gullies which fail to meet the standard should be reshaped and replanted if required
Integrity of waterways	If still required, waterways are still in good working condition	Repair waterways if required

APPENDIX 2: Selected examples of Curragh completion criteria (continued)

3.4 Soil Suitability		
Soil fertility	Monitoring and research results show that levels of soil macro- and micro-nutrients are likely to be sufficient to ensure that trees do not experience nutrient deficiencies (more specific values may be set following several years' monitoring, as agreed in conjunction with the EPA)	Determine the cause of any problems identified, and what corrective actions may be appropriate (e.g. seeding of legumes or application of fertilizer)
Nutrient cycling	Studies conducted on representative rehabilitated areas (e.g. litter decomposition and soil microbiology studies) indicate that nutrient cycling processes are becoming established	Determine the cause of any problems identified, and what corrective actions may be appropriate
3.5 Land Use Suitability		
Suitability for nature conservation	Areas of rehabilitation and unmined sites within the lease, including remnant and regrowth areas from which grazing has been excluded, together possess defined conservation values and could be managed for the purposes of conserving a range of local flora and fauna species and vegetation types, including any rare fauna species	Determine whether further revegetation or other management procedures may be required
Long-term management	Management requirements have been defined (see Criterion 4). Long-term management operations (e.g. maintenance of access tracks, fire) will not be greater than those of areas prior to mining, or where extra management actions may be required, a mechanism has been put in place for addressing these	Develop long-term management plan as in Criterion 4
4. Monitoring and Maintenance Stage		
Monitoring	A monitoring program has been developed that addresses post-closure and post-relinquishment monitoring requirements, and defines responsibilities for conducting monitoring	Address monitoring requirements and responsibilities
Post-closure and post-relinquishment management requirements	A plan for addressing post-closure and post-relinquishment management requirements has been developed in conjunction with the EPA and relevant stakeholders, and responsibility for implementing tasks has been allocated	Develop long-term management plan
Funding	A mechanism for allocating funding required for post-relinquishment management will be developed in conjunction with regulatory authorities, and outlined in the Final Rehabilitation Report	Develop mechanism for addressing funding requirements for post-relinquishment management